AN INVESTIGATION OF THE
PERFORMANCE OF A
COLUMN STABILIZED PLATFORM

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ABSTRACT

The objective of this thesis is to obtain a comparative analysis of various combinations of column configurations for a mobile column stabilized platform. The platform is a deep draft vessel consisting of two longitudinally oriented, cylindrical hulls. To each hull two vertical columns are attached which pierce the surface of the water. The upper ends of the columns are attached to a platform well above the waterline. The platform may provide added performance capabilities in comparison with a standard displacement vessel. The mobile column stabilized platform is not without its problems, however, and this experimental and analytical study provides an analysis of some of these problems.

The resistance characteristics were studied with the use of a model in the M.I.T. Department of Naval Architecture and Marine Engineering Ship Model Towing Tank. A correlation of the data with theory was attempted to obtain interference resistance between the columns. The effect of transverse and longitudinal spacing of the columns, draft, and shape of the columns was investigated and correlation with theory was attempted. The results indicated the parameters of longitudinal spacing and velocity have the most significant effect on interference resistance.

The resistance characteristics of the model are compared with a standard hull form. The constraints imposed by stability and strength requirements on the column shape and size are theoretically calculated.

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NOMENCLATURE

A	- Area
BM	- Distance Between Center of Buoyancy and Metacenter
b	- Transverse Spacing Between Column Centers
C_{DI}	- Interference Drag Coefficient of Columns With the Hulls
C_{DINT}	- Interference Drag Coefficient of Columns
C_{DO}	- Section Drag Coefficient of Columns
C_{DT}	- Wave and Spray Drag Coefficient
C_f	- Friction Drag Coefficient
C_H	- Friction and Form Drag Coefficient of Hulls
C_M	- Inertia Coefficient
C_r	- Residual Drag Coefficient
D	- Diameter of Lower Hull
D_C	- Total Drag of Columns
D_H	- Friction and Form Drag of Lower Hulls
D_I	- Interference Drag Between Columns and Lower Hulls
D_{INT}	- Interference Drag Between Columns
D_O	- Section Drag of Columns
D_T	- Wave and Spray Drag of the Columns
D_W	- Wave Drag of the Hull
E	- Young's Modulus of Elasticity
EHP	- Effective Horsepower
F_C	- Column Froude Number - $V/\sqrt{g L_C}$
F_h	- Hull Froude Number - $V/\sqrt{g L_H}$
F_I	- Inertial Wave Force
GM_T	- Transverse Metacentric Height
H	- Wave Height

h - Distance From Top of Lower Hull to Waterline

H_s - Significant Wave Height

I - Moment of Inertia

k - Radius of Gyration

KB - Center of Buoyancy Above Keel

KG - Center of Gravity Above Keel

L - Length

ℓ - Longitudinal Spacing Between Column Centers

L_H - Length of Lower Hulls

L_C - Horizontal Length of Columns Fore and Aft

P - Pressure

p.c. - Propulsive Coefficient

r - Radius of Curvature

Re - Reynolds Number, VL/ν

t - Thickness

u - Particle Velocity

V - Velocity

x - Horizontal Distance

y - Distance Below Waterline

Δ - Displacement

∇ - Volumetric Displacement

σ - $\sqrt{2\pi g}/\lambda$

σ_{all} - Stress Allowed

σ_b - Bending Stress

σ_c - Compressive Stress

σ_{cr} - Critical Stress

ρ - Density

λ - Wave Length

ν - Kinematic Viscosity

I. INTRODUCTION

In recent years the oil industry has shown an increasing amount of interest in mobile drilling platforms. The primary requirement for oil drilling is a nearly motionless working platform. However, the water depths of new drilling sites have made prohibitive a stationary platform resting on the ocean floor. The most promising type of floating vessel for meeting this requirement is the column stabilized platform. The platforms in use consist of parallel longitudinal hulls or grids with columns extending upward and attached to an upper platform. Presently they are towed to the drilling site and moored.

Recently, two studies were conducted on designs that were similar to the floating oil rigs, but provided increased mobility. References 6 and 13 present the results of these studies on the SEMCAT and TRISEC designs. Both designs employed two submerged hulls with columns connecting the hulls to a platform above the surface.

A mobile platform with little motion in high seas is certainly desireable. Therefore, the following questions arise. Is the concept to be confined to the oil industry, or can it be applied to other missions? If there are other applications, can the job be better performed with the column stabilized mobile platform than the present system or systems in use? A study of this design is necessary to answer these questions.

The configuration to be studied in this paper is similar to the final design considered for the MOHOLE project. The deep draft vessel consists of two streamlined bodies of revolution. Attached to the submerged hulls are vertical columns that pierce the surface of the water and are connected to a platform well above the water's surface. The desireable performance objectives that may be achieved with this configuration are:

a) Freedom to incorporate large decks above the waterline without imposing large resistance penalties.

b) Potential ability to obtain higher rough water speeds than conventional ships.

c) Ability to lower and raise heavy loads at sea between the hulls without subjecting the vessel to large heel angles.

d) Low motion characteristics with smaller response to wave excitations than conventional hull forms.

e) Ability to position the platform vertically to give optimum work height above the water for the existing sea state.

The design of a column stabilized platform is primarily a problem of obtaining a balance between four conflicting factors. These are stability, structural strength, wave motion, and resistance. In the search for an optimum value for one of the above factors, it may not be possible to achieve satisfactory values for the other variables. For example, a smaller column

section area will lower resistance and reduce pitch and heave motions. At the same time, stability will be decreased by lowering the center of buoyancy and decreasing the moment of inertia of the waterplane area. Structural strength also becomes more of a problem.

This study is primarily concerned with the resistance characteristics of the design. The columns are streamlined to reduce the underwater resistance. Interference effects of resistance between bodies, moving through a medium, has been studied in the aerodynamic field. Studies in hydrodynamics attaining conclusive results have been limited to single bodies. The effect on the drag characteristics of varying the following parameters will be studied:

a) Transverse spacing

b) Longitudinal spacing

c) Submergence ratio

d) Column section shape

Because of their importance, the constraints imposed by structural and stability requirements are also determined.

1. Description of the model and dynamometer

The model with six combinations of surface piercing columns was tested in the M.I.T. Ship Model Towing Tank. The plans of the model are shown in Figures I and II on the following pages. The various column shapes are described in Figure III. Each column is twenty one inches long at the center. The lower edge of the column is shaped to conform to the outer surface of the lower hulls.

The lower hulls and columns were finished from pinewood. The shapes were coated with marine paint and final smoothness of the surface was obtained by application of a rubbing compound. A pegboard material was used for the platform deck in order to facilitate the movement of the columns transversely. The holes allow for extension of a rod through the board for attaching the columns. The pegboard is firmly attached to the frame of the platform. A strut with three 1/4" holes allowing attachment of the platform to the hydrofoil dynamometer is located in the center of the platform.

Steel braces are also attached between the upper platform and the upper ends of the column. Attachment of the lower hulls is accomplished by running a twenty four inch rod through the center of the columns. The rod is then screwed into the hulls and the other end attached to the pegboard.

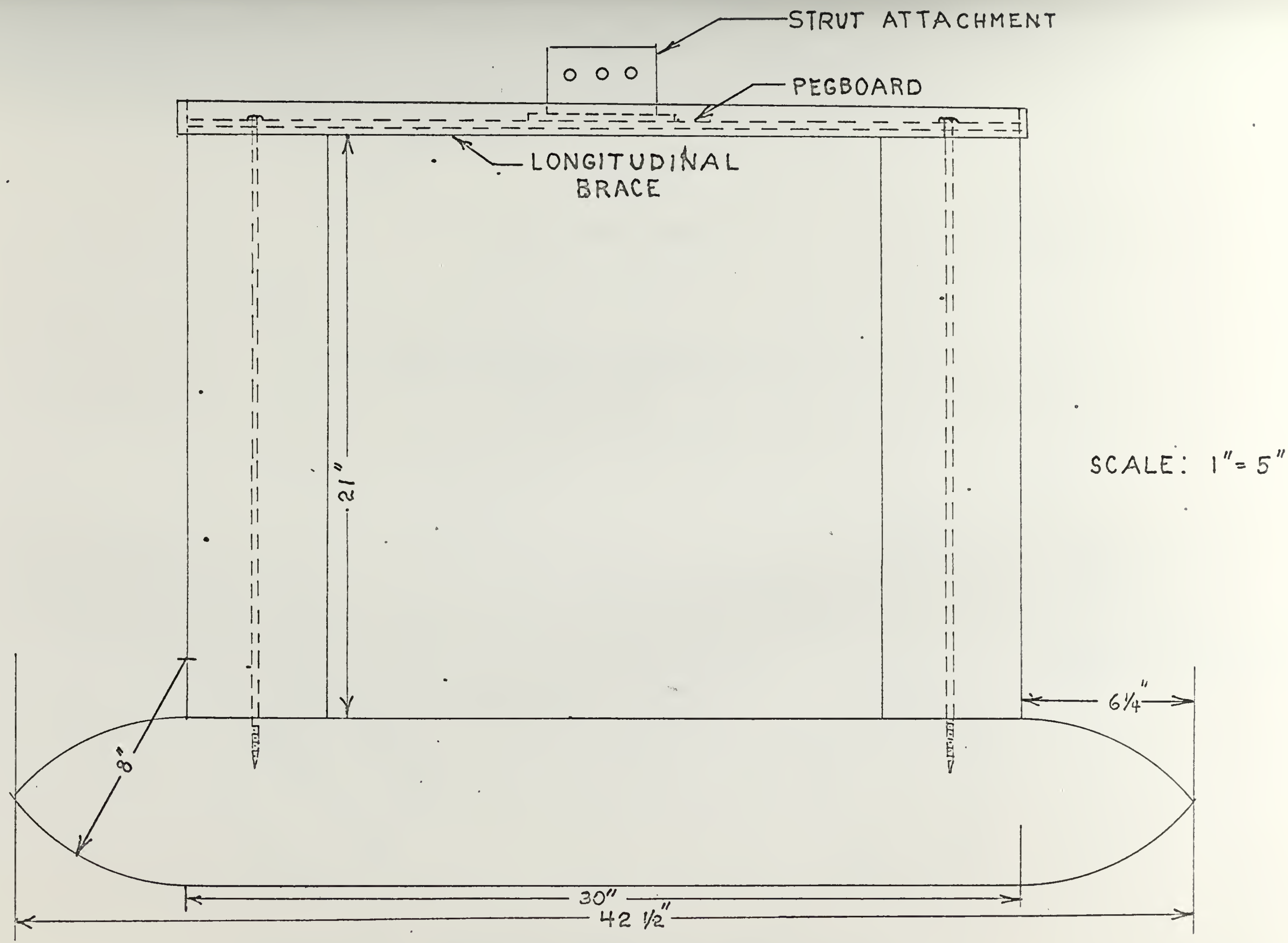


FIGURE I - SIDE VIEW OF TEST MODEL

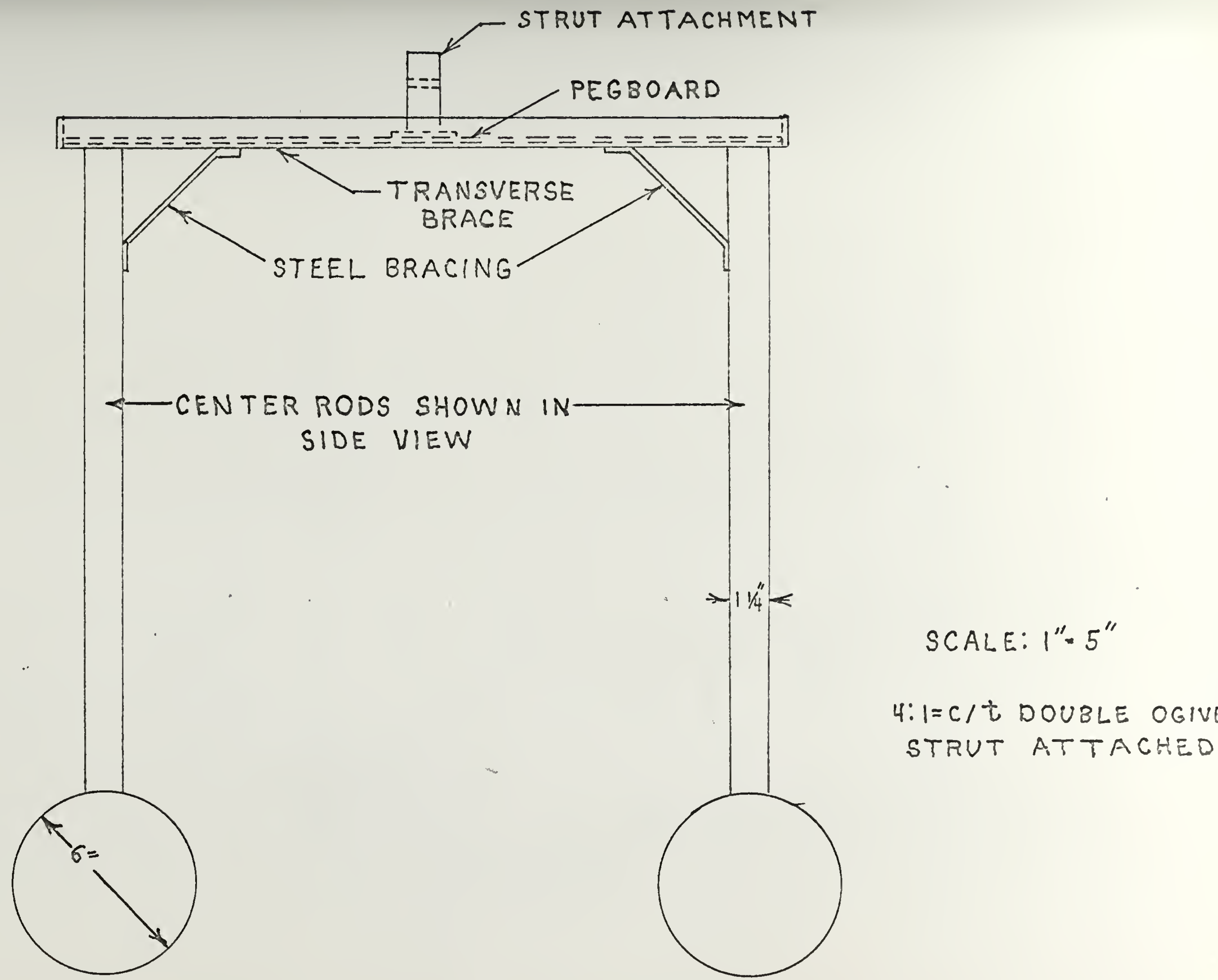


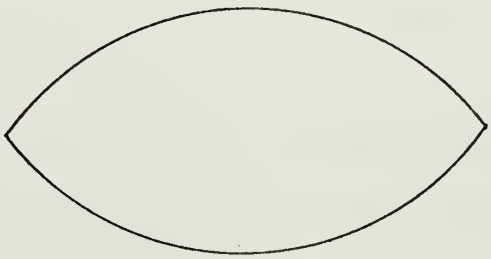
FIGURE II - FRONT VIEW OF TEST MODEL

FIGURE III - COLUMN SHAPES

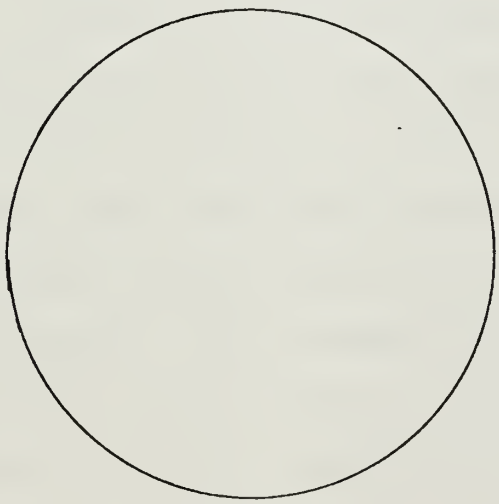
COLUMN A OGIVE $L_c = 5''$ $t = 1''$

COLUMN B OGIVE $L_c = 5''$ $t = 1\ 1/4''$
COLUMN F OGIVE $L_c = 7.5''$ $t = 1.875''$

COLUMN C ELLIPSE $L_c = 5''$ $t = 1\ 1/4''$



COLUMN D OGIVE $L_c = 5''$ $t = 2\ 1/2''$



COLUMN E CIRCLE $L_c = 5''$ $t = 5''$

Reference (5) describes the dynamometer used to measure the drag forces. It was originally thought to measure the resistance by means of a towing bar or cable attached to the platform. The configuration of the model presented a problem when using this method. The large moment that results from the large vertical distance between the center of the drag forces and the point of applying the pulling force created a substantial error in the measurement of the resistance forces. To eliminate this problem the model must be towed at the point where the resultant drag force acts or a measuring apparatus must be used that eliminates the moment error to the drag reading.

The first method would require that the measuring apparatus be submerged. This might result in an undesireable interference drag between it and the model. Hence the second method was adopted.

The only measuring device available at M.I.T. that substantially reduces the error from the moment is the hydrofoil dynamometer. As shown in figure IV on the following page, the drag flexures on the dynamometer are mounted a large distance from the center of the dynamometer structure. This reduces the forces felt due to the large moment at the center. Reference (5) gives results confirming that the effect of the moment on the measurements may be neglected.

One problem that does exist with the hydrofoil dynamometer is the error on the measurement due to carriage

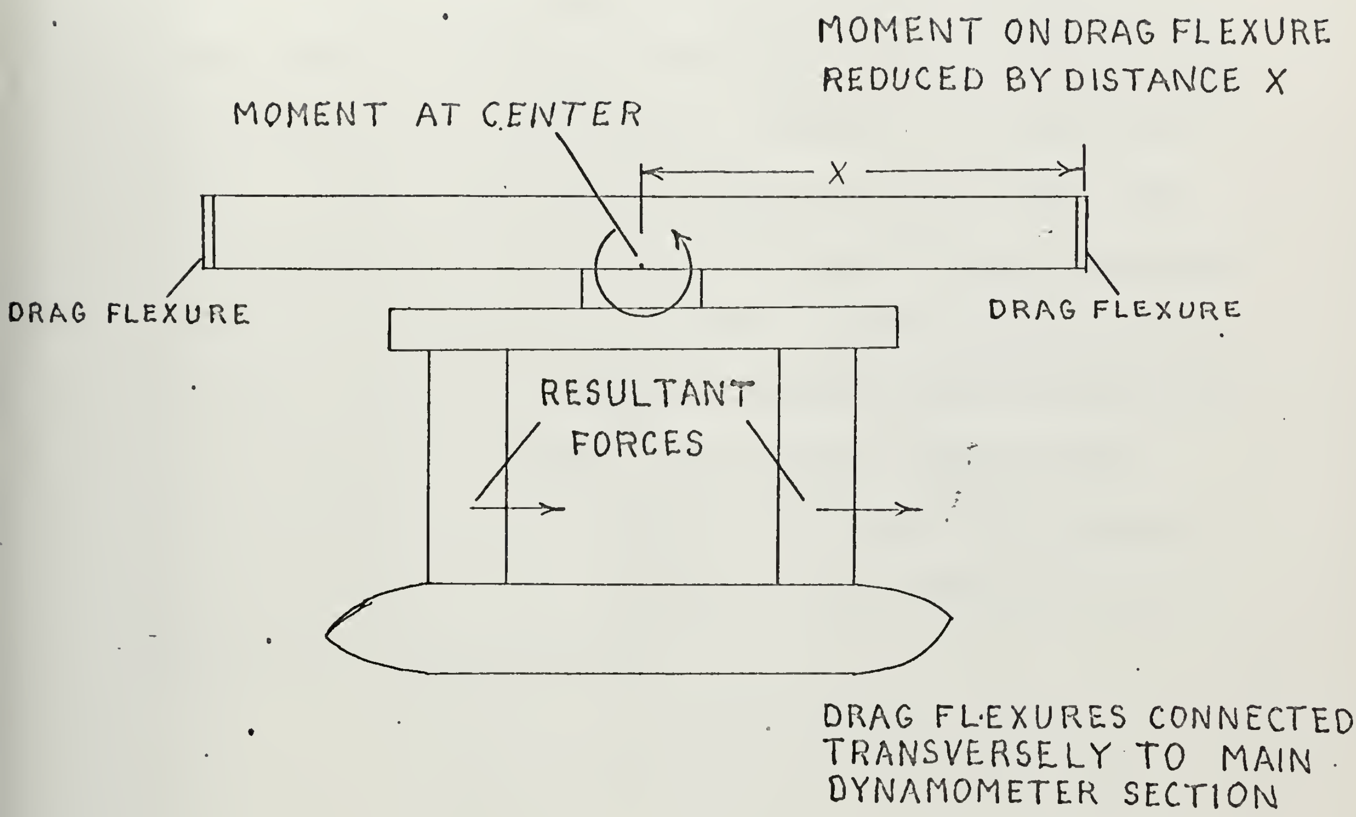


FIGURE IV - MODEL ATTACHED TO DYNAMOMETER

oscillations. Two dampers were attached to the dynamometer to eliminate added drag counts resulting from oscillations in the towing carriage. The dynamometer was calibrated prior to each set of runs. There was negligible drift throughout the testing.

With the model firmly attached to the carriage the desired drafts were obtained by raising or lowering the water level in the tank. The depth of water to the top of the lower hulls was varied between 9, 12, and 17.75 inches. Runs were made at speeds of 1.13, 2.06, 3.31, and 4.97 knots. Photocells were used to determine exact times for completion of each run. Tests were conducted with the transverse distances between column centers set at 15, 18, and 21 inches, and with the longitudinal spacing between column centers set to give ℓ/L_C values of 2.0, 3.0, and 5.0. Results of the towing tests are presented in Section II-3.

2. Procedure

The total drag of the model was divided into the following components:

(1) Section drag of the columns, D_O

(2) Hull frictional and form drag, D_H

(3) Wave drag from the hull, D_W

(4) Wave drag and spray drag of the columns, D_T

(5) Interference drag between the columns and the lower hulls, D_I

(6) Interference drag between the columns, D_{INT}

(7) Total column drag, $D_C = D_O + D_T + D_I + D_{INT}$

The procedure to determine the interference drag between the columns is outlined in the following steps:

(1) The hull frictional drag was determined by first finding the friction coefficient for the hull:

$$C_f = .075/(\log Re-2)^2 \qquad (1.1)$$

Where Re = Reynolds Number, VL/ν

Then using equation (9.2) of ref. (12) to obtain the frictional plus form drag:

$$C_H = C_f \left[1+1/2\ (D/L_H) + 6(D/L_H)^4\right] \qquad (1.2)$$

Where D = hull diameter and L_H = hull length. The hull frictional and form resistance was obtained, using C_H and wetted surface area of the hulls.

(2) The hull wave drag was computed using figure 9.2 of ref. (12). This drag is a function of Froude number and submergence ratio.

(3) The sum of the results of steps (1) and (2) are subtracted from the measured total drag, and the difference is plotted as total column drag in figures V through X, as a function of submergence ratio. If a line is extended through these points to a submergence ratio equal to zero, the reading will be the total column drag, D_C minus the column section drag D_O, or $D_C - D_O = D_T + D_I + D_{INT}$.

(4) The theoretical wave and spray drag, D_T, of the columns, based on column thickness, is obtained from figure 24 of ref. (10). The drag for the hull-column interaction, D_I, is obtained using equation 12 on page 8-10 in ref. (10), which is also based on column thickness. The sum of these two drag components subtracted from $D_C - D_O$ obtained in the previous step is the column interference drag, D_{INT}, which is the sought for result.

3. Presentation of Results

Table I in this section is a summary of the data extracted from results of the towing tests for evaluation of the concept. All data was recorded on the digital counter at the M.I.T. Ship Model Towing Tank.

Figures V to X present the total resistance of the columns as a function of the submergence ratio, h/D where h is the distance between the upper edge of the lower hull and the waterline and D is the diameter of the lower hulls. The column resistance was obtained as explained in the preceding section. The lines shown in figures V through X connect the values of total column drag of each column shape. The values of total column resistance less the section drag of the columns correspond to the point where the lines representing column resistance cross zero submergence. These values of drag, as well as the calculated values of D_T, D_I, and D_{INT}, are tabulated in Table II and Table III of this section. Table II shows the results for five of the column shapes and for an ℓ/L_C = 5.0. The graphical presentation of the results tabulated in Table II may be seen in figure XI for columns A, B, C, and F. Table III and figure XII show similar results for an ℓ/L_C = 3.0. Table IV and figure XIII show how the total model drag is distributed among the various drag components for column shape B at h/D = 1.5 and ℓ/L_C = 5.0.

TABLE I

SUMMARY OF RESISTANCE DATA

Run No.	Column Section Shape (see fig. III)	Longitudinal Spacing between Columns, ℓ, in inches	Transverse Spacing between Columns, b, in inches	Distance between Waterline and Lower Hulls, h, in inches	Velocity, V, in ft./sec.	Total Measured Drag, lbs.
1	A	25	21	17.75	1.932	0.780
2	A	25	21	17.75	3.508	1.830
3	A	25	21	17.75	5.690	3.810
4	A	25	21	17.75	8.420	8.530
5	A	25	18	17.75	1.932	0.802
6	A	25	18	17.75	3.508	1.941
7	A	25	18	17.75	5.690	4.050
8	A	25	18	17.75	8.190	8.190
9	A	25	15	17.75	1.932	0.750
10	A	25	15	17.75	3.508	1.990
11	A	25	15	17.75	5.690	4.050
12	A	25	15	17.75	8.382	8.770
13	A	25	15	12.00	1.932	0.720
14	A	25	15	12.00	3.508	1.810
15	A	25	15	12.00	5.690	4.230
16	A	25	15	12.00	8.442	8.030
17	A	25	18	12.00	1.932	0.658
18	A	25	18	12.00	3.508	1.720
19	A	25	18	12.00	5.629	4.140
20	A	25	18	12.00	8.448	8.010
21	A	25	21	12.00	1.932	0.649
22	A	25	21	12.00	3.508	1.698
23	A	25	21	12.00	5.690	3.975
24	A	25	21	12.00	7.980	7.980
25	A	25	21	9.00	1.932	0.684
26	A	25	21	9.00	3.508	1.705
27	A	25	21	9.00	5.625	4.330
28	A	25	21	9.00	8.442	7.500
29	A	25	18	9.00	1.932	0.623
30	A	25	18	9.00	3.508	1.735
31	A	25	18	9.00	5.690	4.560
32	A	25	18	9.00	8.447	7.930
33	A	25	15	9.00	1.932	0.587
34	A	25	15	9.00	3.508	1.720
35	A	25	15	9.00	5.579	4.840
36	A	25	15	9.00	8.420	7.820

Run no.	Column Section Shape (see fig. III)	Longitudinal Spacing between Columns, ℓ, in inches	Transverse Spacing between Columns, b, in inches	Distance between Waterline and Lower Hulls, h, in inches	Velocity, V, in ft./sec.	Total Measured Drag, lbs.
37	E	25	21	9.00	1.932	4.790
38	E	25	21	9.00	1.932	4.050
39	E	25	21	9.00	1.932	5.150
40	E	25	21	9.00	3.508	14.80
41	E	25	21	9.00	3.507	13.85
42	E	25	21	9.00	3.508	14.70
43	E	25	17	9.00	1.932	5.780
44	E	25	17	9.00	1.932	5.420
45	E	25	17	9.00	1.932	5.430
46	E	25	17	9.00	3.508	13.70
47	E	25	17	9.00	3.508	15.30
48	E	25	17	9.00	3.508	17.30
49	E	25	17	9.00	5.623	29.60
50	E	25	17	12.00	1.932	6.80
51	E	25	17	12.00	3.507	19.75
52	E	25	21	12.00	1.932	8.50
53	E	25	21	12.00	3.509	16.65
54	E	25	21	17.75	1.932	8.53
55	C	25	15	17.75	1.932	0.804
56	C	25	15	17.75	3.505	2.381
57	C	25	15	17.75	5.567	4.610
58	C	25	15	17.75	8.168	9.900
59	C	25	18	17.75	1.932	0.815
60	C	25	18	17.75	3.505	2.442
61	C	25	18	17.75	5.567	4.870
62	C	25	18	17.75	9.742	10.81
63	C	25	21	17.75	1.932	0.811
64	C	25	21	17.75	3.509	2.482
65	C	25	21	17.75	5.625	4.660
66	C	25	21	17.75	8.255	9.570
67	C	25	21	12.00	1.932	0.725
68	C	25	21	12.00	3.500	2.141
69	C	25	21	12.00	5.631	4.680
70	C	25	21	12.00	8.166	8.760
71	C	25	18	12.00	1.932	0.709
72	C	25	18	12.00	3.508	2.105
73	C	25	18	12.00	5.690	4.510
74	C	25	18	12.00	8.177	8.650

Run No.	Column Section Shape (see fig. III)	Longitudinal Spacing between Columns, ℓ, in inches	Transverse Spacing between Columns, b, in inches	Distance between Waterline and Lower Hulls, h, in inches	Velocity, V, in ft./sec.	Total Measured Drag, lbs.
75	C	25	15	12.00	1.932	0.709
76	C	25	15	12.00	3.508	2.281
77	C	25	15	12.00	5.690	4.670
78	C	25	15	12.00	8.549	9.380
79	C	25	15	9.00	1.932	0.584
80	C	25	15	9.00	3.505	2.140
81	C	25	15	9.00	5.613	4.850
82	C	25	15	9.00	8.549	9.250
83	C	25	18	9.00	1.932	0.539
84	C	25	18	9.00	3.503	1.970
85	C	25	18	9.00	5.633	4.760
86	C	25	18	9.00	8.408	8.500
87	C	25	21	9.00	1.932	0.608
88	C	25	21	9.00	3.505	2.115
89	C	25	21	9.00	5.688	4.920
90	C	25	21	9.00	8.325	8.710
91	B	25	15	9.00	1.932	0.600
92	B	25	15	9.00	3.508	1.805
93	B	25	15	9.00	5.690	4.480
94	B	25	15	9.00	8.410	8.125
95	B	25	18	9.00	1.932	0.602
96	B	25	18	9.00	3.508	1.685
97	B	25	18	9.00	5.690	4.525
98	B	25	18	9.00	8.420	8.000
99	B	25	21	9.00	1.932	0.693
100	B	25	21	9.00	3.508	1.812
101	B	25	21	9.00	5.690	4.325
102	B	25	21	9.00	8.410	7.960
103	B	25	21	12.00	1.932	0.740
104	B	25	21	12.00	3.508	1.905
105	B	25	21	12.00	5.690	4.070
106	B	25	21	12.00	8.410	7.750
107	B	25	18	12.00	1.932	0.701
108	B	25	18	12.00	3.508	1.752
109	B	25	18	12.00	5.690	3.900
110	B	25	18	12.00	8.408	7.810
111	B	25	15	12.00	1.932	0.700
112	B	25	15	12.00	3.508	1.865
113	B	25	15	12.00	5.690	3.940
114	B	25	15	12.00	8.408	7.750

Run No.	Column Section Shape (see fig. III)	Longitudinal Spacing between Columns, ℓ, in inches	Transverse Spacing between Columns, b, in inches	Distance between Waterline and Lower Hulls, h, in inches	Velocity, V, in ft./sec.	Total Measured Drag, lbs.
115	B	25	15	17.75	1.932	0.779
116	B	25	15	17.75	3.508	2.040
117	B	25	15	17.75	5.690	3.740
118	B	25	15	17.75	8.408	8.650
119	B	25	18	17.75	1.932	0.855
120	B	25	18	17.75	3.508	2.110
121	B	25	18	17.75	5.690	3.900
122	B	25	18	17.75	8.408	9.180
123	B	25	21	17.75	1.932	0.894
124	B	25	21	17.75	3.508	2.155
125	B	25	21	17.75	5.690	4.020
126	B	25	21	17.75	8.408	8.850
127	D	25	15	17.75	1.932	2.440
128	D	25	15	17.75	3.508	6.905
129	D	25	15	17.75	5.690	9.910
130	D	25	15	17.75	8.408	23.550
131	D	25	18	17.75	1.932	2.456
132	D	25	18	17.75	3.508	7.670
133	D	25	18	17.75	5.690	11.110
134	D	25	18	17.75	8.408	22.400
135	D	25	21	17.75	1.932	2.322
136	D	25	21	17.75	3.508	7.660
137	D	25	21	17.75	5.690	9.150
138	D	25	21	17.75	8.408	20.400
139	D	25	21	12.00	1.932	1.721
140	D	25	21	12.00	3.508	6.195
141	D	25	21	12.00	5.690	8.510
142	D	25	21	12.00	8.408	16.000
143	D	25	18	12.00	1.932	1.675
144	D	25	18	12.00	3.508	6.150
145	D	25	18	12.00	5.690	8.080
146	D	25	18	12.00	8.408	16.310
147	D	25	15	12.00	1.932	1.740
148	D	25	15	12.00	3.508	6.110
149	D	25	15	12.00	5.690	9.140
150	D	25	15	12.00	8.408	14.000

Run No.	Column Section Shape (see fig. III)	Longitudinal Spacing between Columns, ℓ, in inches	Transverse Spacing between Columns, b, in inches	Distance between Waterline and Lower Hulls, h, in inches	Velocity, V, in ft./sec.	Total Measured Drag, lbs.
151	D	25	15	9.00	1.932	1.495
152	D	25	15	9.00	3.508	4.945
153	D	25	15	9.00	5.690	7.850
154	D	25	15	9.00	8.408	13.900
155	D	25	18	9.00	1.932	1.498
156	D	25	18	9.00	3.508	5.230
157	D	25	18	9.00	5.690	7.630
158	D	25	18	9.00	8.408	15.750
159	D	25	21	9.00	1.932	1.595
160	D	25	21	9.00	3.508	5.400
161	D	25	21	9.00	5.690	8.000
162	D	25	21	9.00	8.408	13.540
163	A	15	15	17.75	1.932	1.149
164	A	15	15	17.75	3.509	2.138
165	A	15	15	17.75	5.609	4.970
166	A	15	18	17.75	1.932	1.348
167	A	15	18	17.75	3.509	2.520
168	A	15	18	17.75	5.690	4.910
169	A	15	21	17.75	1.932	1.100
170	A	15	21	17.75	3.509	2.260
171	A	15	21	17.75	5.635	4.640
172	A	15	21	12.00	1.932	0.926
173	A	15	21	12.00	3.509	1.915
174	A	15	21	12.00	5.690	4.790
175	A	15	21	12.00	8.198	8.340
176	A	15	18	12.00	1.932	1.050
177	A	15	18	12.00	3.509	2.040
178	A	15	18	12.00	5.690	4.890
179	A	15	18	12.00	8.198	8.630
180	A	15	15	12.00	1.932	1.040
181	A	15	15	12.00	3.509	2.018
182	A	15	15	12.00	5.690	5.040
183	A	15	15	9.00	1.932	1.100
184	A	15	15	9.00	3.509	2.050
185	A	15	15	9.00	5.609	4.325
186	A	15	15	9.00	8.198	7.84

Run No.	Column Section Shape (see fig. III)	Longitudinal Spacing between Columns, ℓ, in inches	Transverse Spacing between Columns, b, in inches	Distance between Waterline and Lower Hulls, h, in inches	Velocity, V, in ft./sec.	Total Measured Drag, lbs.
187	A	15	18	9.00	1.932	1.089
188	A	15	18	9.00	3.509	1.986
189	A	15	18	9.00	5.660	5.370
190	A	15	18	9.00	8.141	8.230
191	A	15	21	9.00	1.932	1.000
192	A	15	21	9.00	3.509	1.914
193	A	15	21	9.00	5.633	5.260
194	A	15	21	9.00	8.460	7.790
195	B	15	21	9.00	1.932	0.832
196	B	15	21	9.00	3.509	1.822
197	B	15	21	9.00	5.633	5.290
198	B	15	21	9.00	7.800	11.520
199	B	15	18	9.00	3.509	2.870
200	B	15	18	9.00	5.633	5.375
201	B	15	18	9.00	8.460	9.310
202	B	15	15	9.00	3.509	1.780
203	B	15	15	9.00	5.633	5.425
204	B	15	15	9.00	8.444	9.476
205	B	15	15	12.00	3.509	1.748
206	B	15	15	12.00	5.633	5.56
207	B	15	15	12.00	8.306	10.450
208	B	15	18	12.00	3.510	1.584
209	B	15	18	12.00	5.635	4.849
210	B	15	18	12.00	8.163	10.470
211	B	15	21	12.00	1.932	0.788
212	B	15	21	12.00	3.510	2.160
213	B	15	21	12.00	5.635	5.540
214	C	15	15	12.00	1.932	0.822
215	C	15	15	12.00	3.510	4.460
216	C	15	15	12.00	5.635	5.940
217	C	15	15	12.00	8.449	10.310
218	C	15	18	12.00	3.510	3.795
219	C	15	18	12.00	5.635	7.000
220	C	15	18	12.00	8.449	11.170
221	C	15	21	12.00	1.932	0.970
222	C	15	21	12.00	3.510	2.580
223	C	15	21	12.00	5.636	5.810
224	C	15	21	12.00	8.332	10.630

Run No.	Column Section Shape (see fig. III)	Longitudinal Spacing between Columns, ℓ, in inches	Transverse Spacing between Columns, b, in inches	Distance between Waterline and Lower Hulls, h, in inches	Velocity, V, in ft./sec.	Total Measured Drag, lbs.
225	C	15	21	17.75	3.510	2.932
226	C	15	21	17.75	5.636	6.120
227	C	15	21	17.75	8.457	13.910
228	C	15	18	17.75	1.932	0.857
229	C	15	18	17.75	3.510	3.190
230	C	15	18	17.75	5.635	6.070
231	C	15	21	17.75	1.932	0.991
232	C	15	21	17.75	3.510	2.718
233	C	15	21	17.75	5.635	7.010
234	D	15	15	17.75	1.932	2.759
235	D	15	15	17.75	3.510	8.010
236	D	15	15	17.75	5.635	13.290
237	D	15	18	17.75	1.932	2.840
238	D	15	18	17.75	3.510	8.100
239	D	15	18	17.75	5.826	12.510
240	D	15	18	12.00	1.932	1.561
241	D	15	18	12.00	3.510	6.280
242	D	15	18	12.00	5.826	10.140
243	D	15	21	12.00	1.932	2.090
244	D	15	21	12.00	3.510	5.730
245	D	15	21	12.00	5.826	10.730
246	D	15	21	9.00	1.932	1.570
247	D	15	21	9.00	3.510	5.090
248	D	15	21	9.00	5.613	9.990
249	D	15	21	9.00	8.448	14.120
250	D	15	18	9.00	1.932	1.665
251	D	15	18	9.00	3.510	5.010
252	D	15	18	9.00	5.635	10.160
253	D	15	18	9.00	8.448	16.000
254	D	15	15	9.00	1.932	1.812
255	D	15	15	9.00	3.510	5.130
256	D	15	15	9.00	5.635	10.480
257	D	15	15	9.00	8.458	16.700
258	F	22	15	9.00	1.932	0.926
259	F	22	15	9.00	3.507	3.890
260	F	22	15	9.00	5.635	6.450
261	F	22	15	9.00	8.450	11.080

Run No.	Column Section Shape (see fig. III)	Longitudinal Spacing between Columns, ℓ, in inches	Transverse Spacing between Columns, b, in inches	Distance between Waterline and Lower Hulls, h, in inches	Velocity, V, in ft./sec.	Total Measured Drag, lbs.
262	F	22	18	9.00	1.932	0.813
263	F	22	18	9.00	3.508	3.815
264	F	22	18	9.00	5.635	7.670
265	F	22	18	9.00	8.444	21.700
266	F	22	21	9.00	1.932	0.784
267	F	22	21	9.00	3.508	3.830
268	F	22	21	9.00	5.635	6.620
269	F	22	21	9.00	8.221	22.120
270	F	22	21	12.00	1.932	0.723
271	F	22	21	12.00	3.509	3.735
272	F	22	21	12.00	5.635	5.780
273	F	22	18	12.00	1.932	1.040
274	F	22	18	12.00	3.510	4.250
275	F	22	18	12.00	5.635	6.380
276	F	22	15	12.00	1.932	1.020
277	F	22	15	12.00	3.509	4.090
278	F	22	15	12.00	5.635	6.190
279	F	14	15	12.00	1.932	0.605
280	F	14	15	12.00	3.509	2.390
281	F	14	15	12.00	5.635	6.400
282	F	14	18	12.00	1.932	0.961
283	F	14	18	12.00	3.509	2.590
284	F	14	18	12.00	5.635	6.320
285	F	14	21	12.00	1.932	0.862
286	F	14	21	12.00	3.509	2.940
287	F	14	21	12.00	5.635	6.460
288	F	14	21	12.00	8.461	12.610
289	F	14	15	9.00	1.932	1.020
290	F	14	15	9.00	3.510	2.780
291	F	14	15	9.00	5.635	6.820
292	F	14	15	9.00	8.460	11.320
293	F	14	18	9.00	1.932	0.772
294	F	14	18	9.00	3.510	2.622
295	F	14	18	9.00	5.635	6.900
296	F	14	18	9.00	8.459	10.350
297	F	14	21	9.00	1.932	0.818
298	F	14	21	9.00	3.510	2.700
299	F	14	21	9.00	5.635	7.330

Run No.	Column Section Shape (see fig. III)	Longitudinal Spacing between Columns, ℓ, in inches	Transverse Spacing between Columns, b, in inches	Distance between Waterline and Lower Hulls, h, in inches	Velocity, V, in ft./sec.	Total Measured Drag, lbs.
300	B	10	21	9.00	1.932	0.709
301	B	10	21	9.00	3.510	1.698
302	B	10	21	9.00	5.635	5.660
303	B	10	21	9.00	8.457	9.210
304	B	10	18	12.00	1.932	0.823
305	B	10	18	12.00	3.510	1.802
306	B	10	18	12.00	5.635	5.390
307	B	10	18	12.00	8.457	9.160
308	B	10	15	17.75	1.032	0.877
309	B	10	15	17.75	3.510	2.020
310	B	10	15	17.75	5.635	5.320
311	B	10	15	17.75	8.433	9.000

FIGURE V

TOTAL COLUMN DRAG FOR COLUMNS A, B, AND C AT A FROUDE NUMBER, F_C, = 0.526

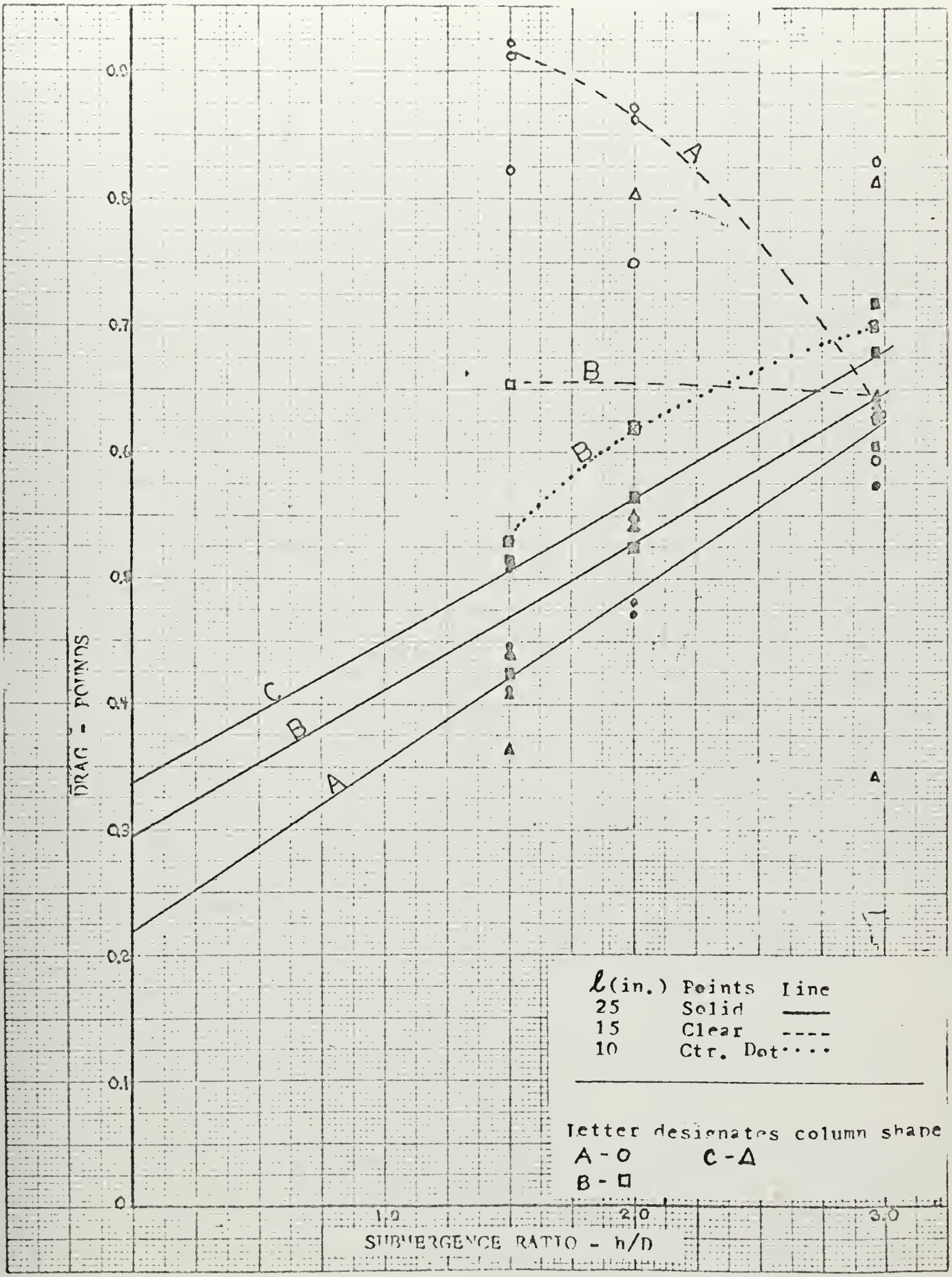


FIGURE VI

TOTAL COLUMN DRAG FOR COLUMNS A,B, AND C AT A FROUDE NUMBER, F_C, = 0.955

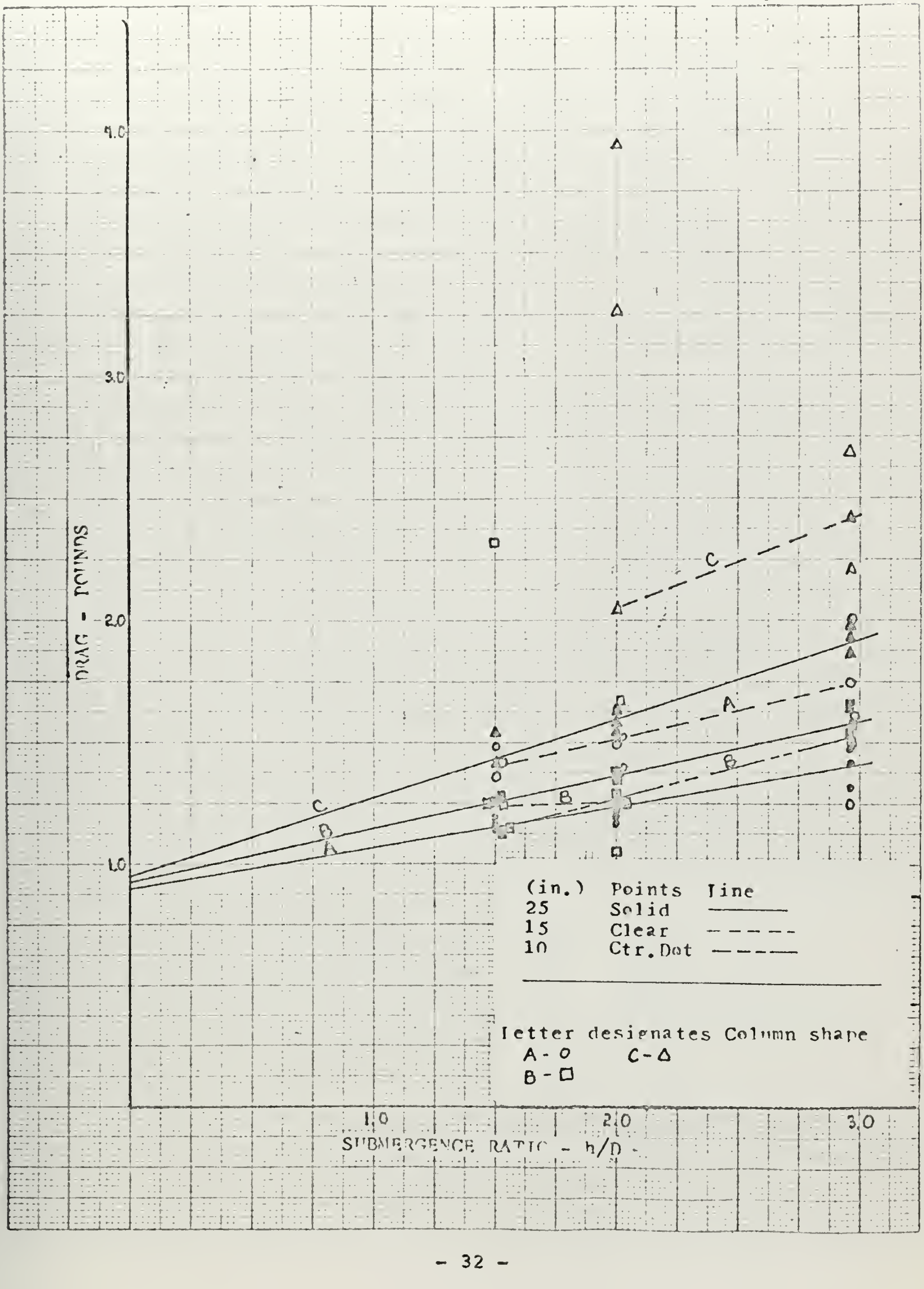


FIGURE VII

TOTAL COLUMN DRAG FOR COLUMNS A, B, AND C AT A FROUDE NUMBER, F_C, = 1.545

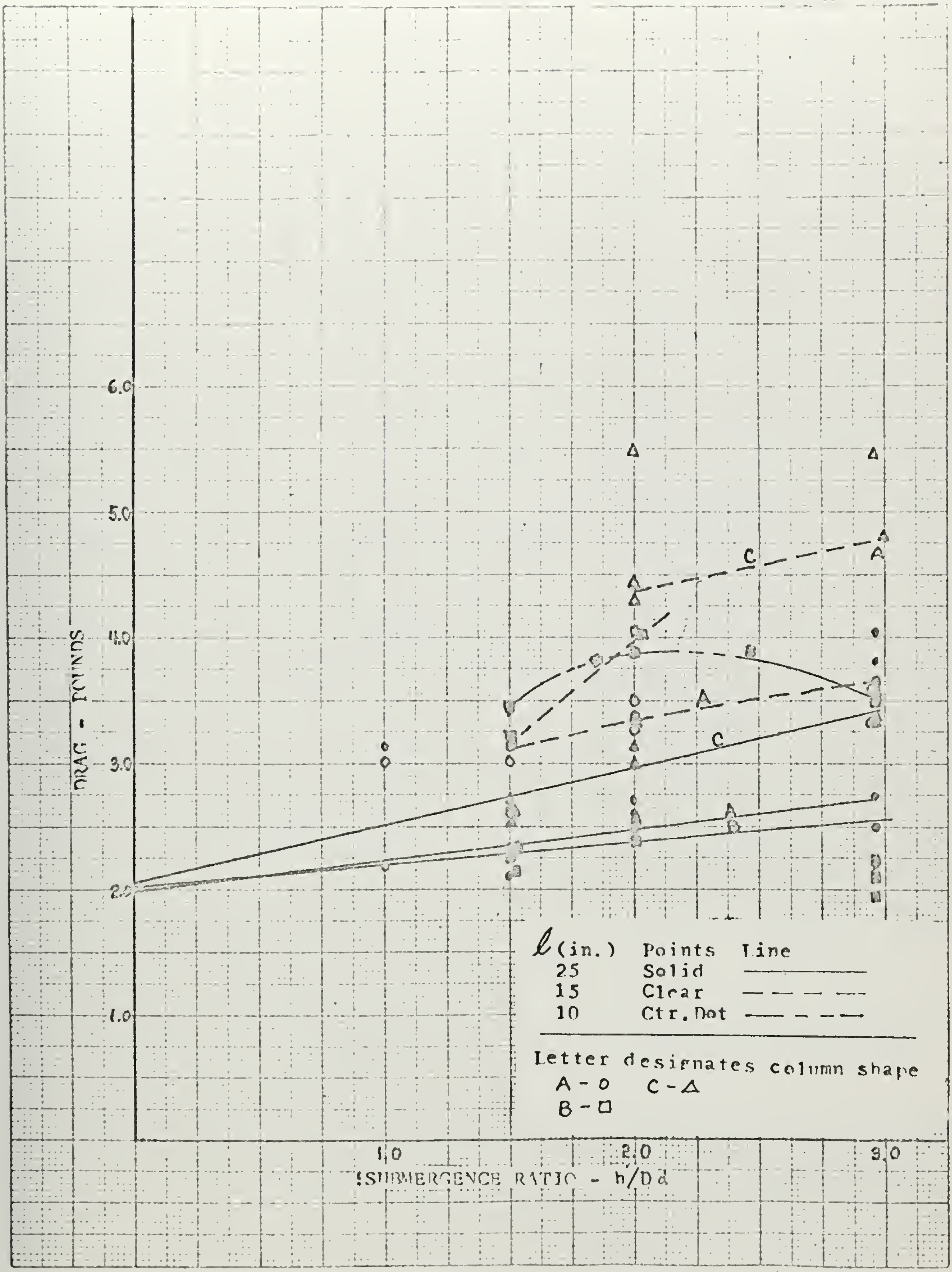


FIGURE VIII
TOTAL COLUMN DRAG FOR COLUMNS A, B, AND C AT A FROUDE NUMBER, F_C, = 2.28

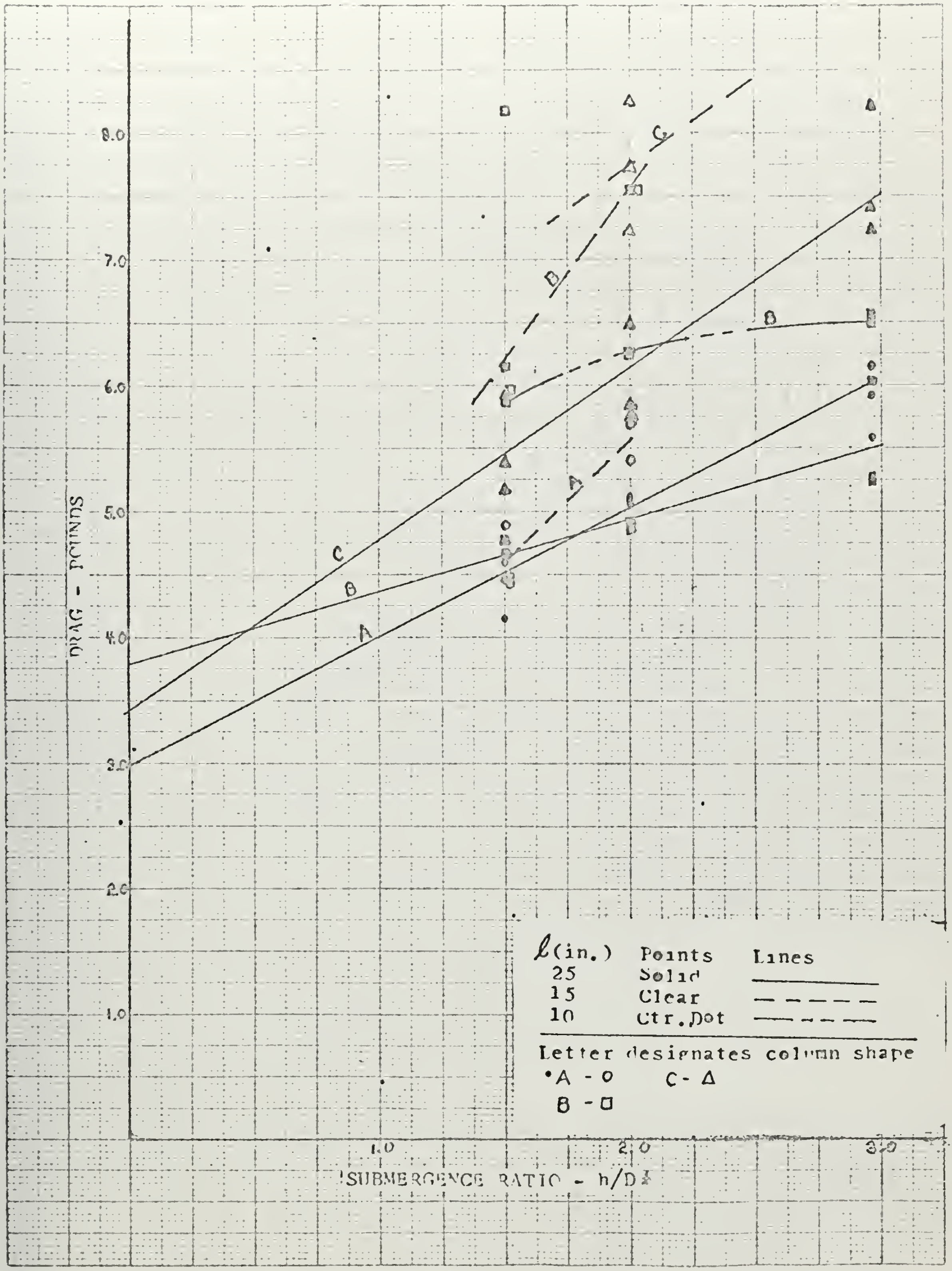


FIGURE IX
TOTAL COLUMN DRAG FOR COLUMNS D AND F AT LOW VELOCITIES

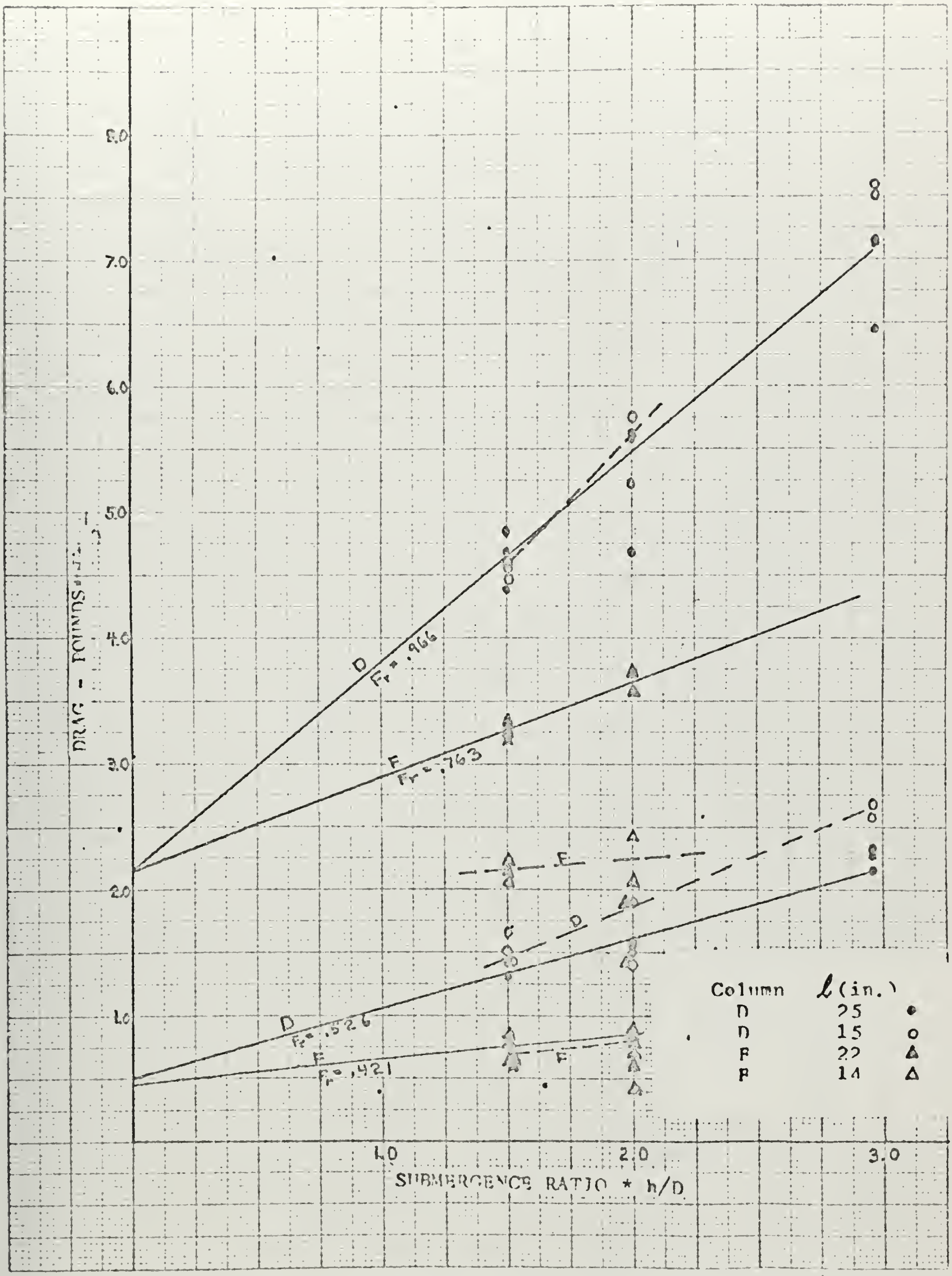


FIGURE X

TOTAL COLUMN DRAG FOR COLUMNS D AND F AT HIGH VELOCITIES

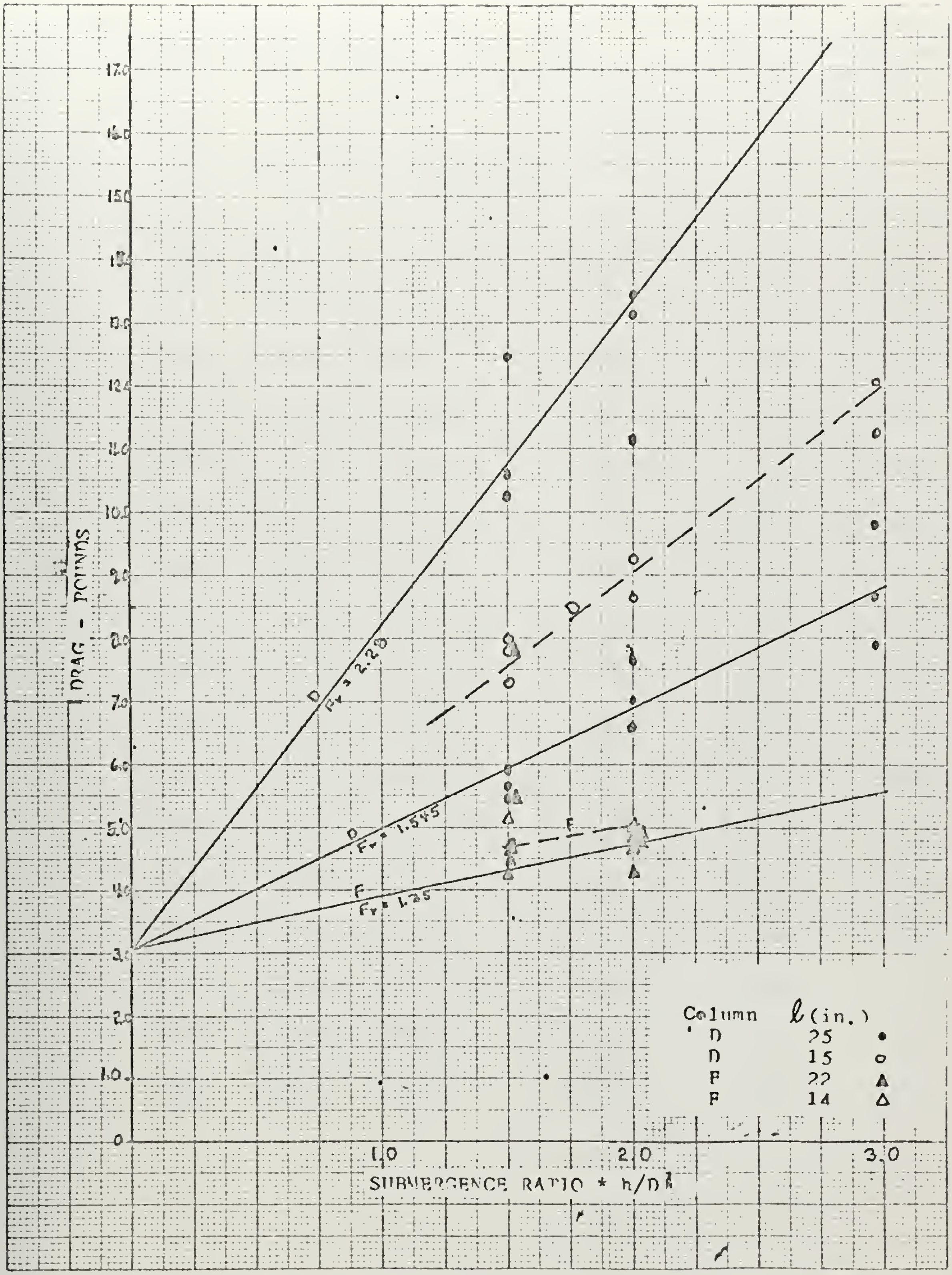


TABLE II

COLUMN INTERFERENCE DRAG FOR $\ell / L_C = 5.0$

Column Shape	Total Measured Drag, lbs.	Froude Number, F_C	Wave and Spray Drag Coefficient, C_{DT}	Interference Drag Coefficient of Columns with Hulls, C_{DI}	$D_T + D_I$ in lbs.	Interference Drag between Columns, D_{INT} in lbs.
A	0.220	0.526	1.45	0.150	0.150	0.0698
B	0.295	0.526	1.45	0.187	0.255	0.154
C	0.335	0.526	1.45	0.187	0.255	0.194
D	0.520	0.526	1.45	0.375	1.098	-0.570
F	0.421	0.450	1.20	0.187	0.478	-0.064
A	0.920	0.955	0.70	0.150	0.280	0.640
B	0.940	0.955	0.70	0.187	0.455	0.485
C	0.960	0.955	0.70	0.187	0.455	0.505
D	2.170	0.955	0.70	0.375	2.210	-0.040
F	2.150	0.763	1.20	0.187	1.610	0.409
A	1.990	1.545	0.22	0.150	0.316	1.674
B	2.000	1.545	0.22	0.187	0.522	1.478
C	2.020	1.545	0.22	0.187	0.522	1.480
D	3.000	1.545	0.22	0.375	2.810	0.190
F	3.000	1.350	0.38	0.187	1.640	1.360
A	3.000	2.280	0.20	0.150	0.654	2.346
B	3.800	2.280	0.20	0.187	1.620	2.180
C	3.500	2.280	0.20	0.187	1.620	1.880

TABLE III

COLUMN INTERFERENCE DRAG FOR $\ell/L_C = 3.0$

Column Shape	Change in Drag From ℓ/L_C =5.0	Total Measured Drag	Froude Number, F_C
A	0.200	0.2698	0.526
A	0.200	0.840	0.955
B	-0.130	0.355	0.955
C	0.450	0.945	0.955
F	-0.050	0.014	0.421
F	-1.000	-0.591	0.763
A	1.540	3.214	1.545
B	1.735	3.213	1.545
C	1.905	3.385	1.545
F	0.400	1.760	1.350
A	0.300	2.646	2.280
B	2.050	4.230	2.280
C	1.600	3.480	2.280

FIGURE XI

COLUMN INTERFERENCE DRAG VS. FROUDE NUMBER - $\ell/L_C = 5.0$

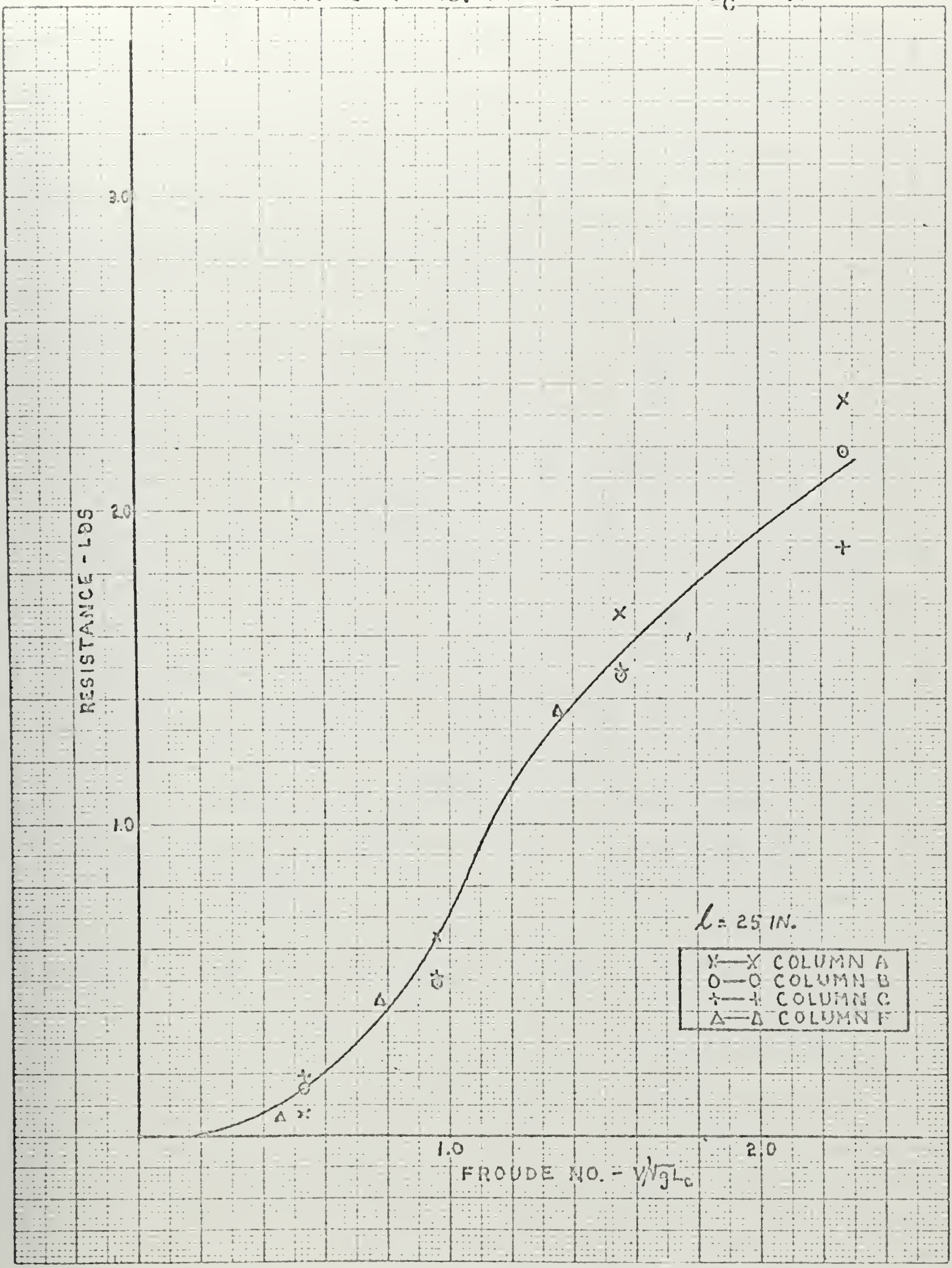


FIGURE XII

COLUMN INTERFERENCE DRAG VS. FROUDE NUMBER - $l/L_C = 3.0$

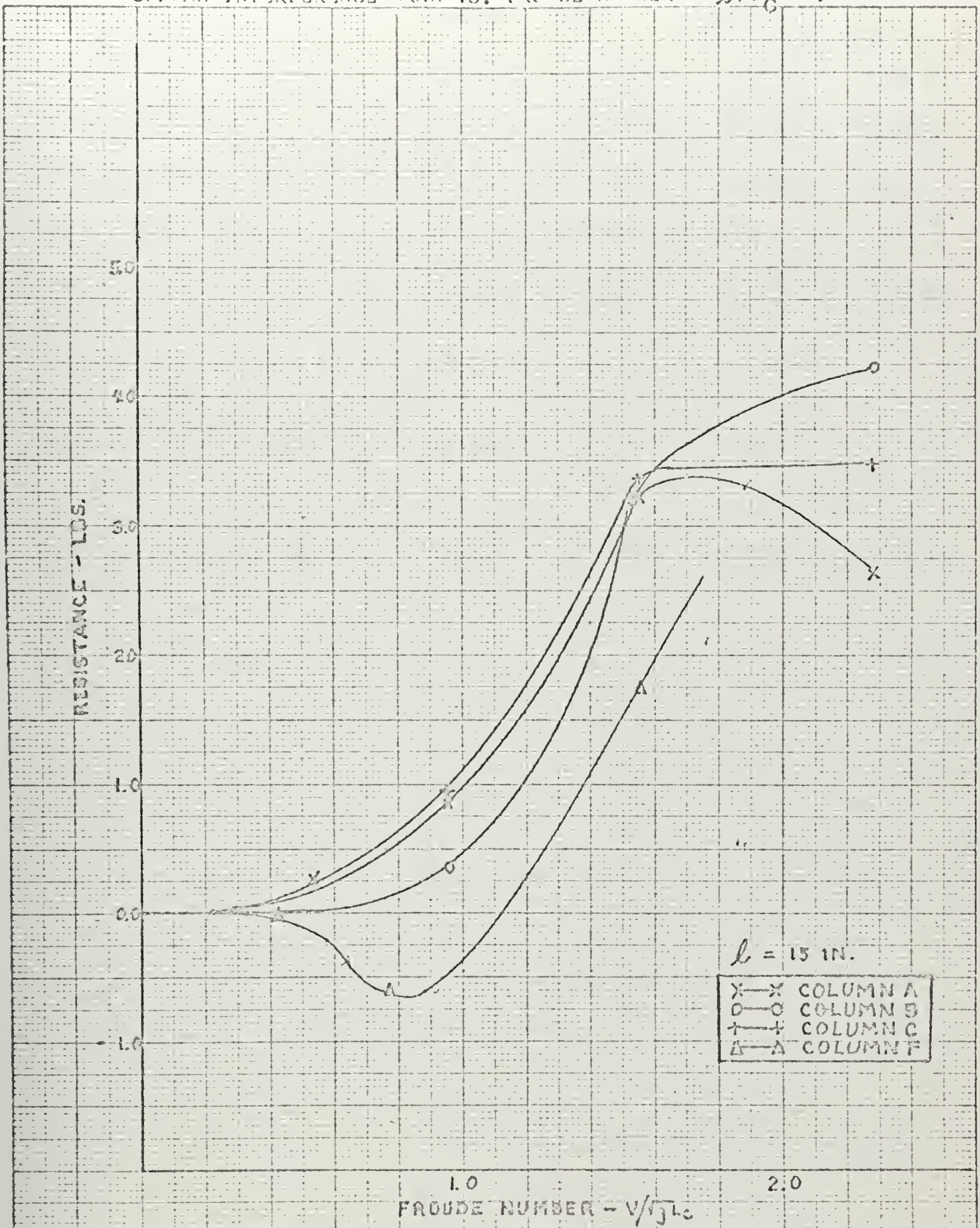
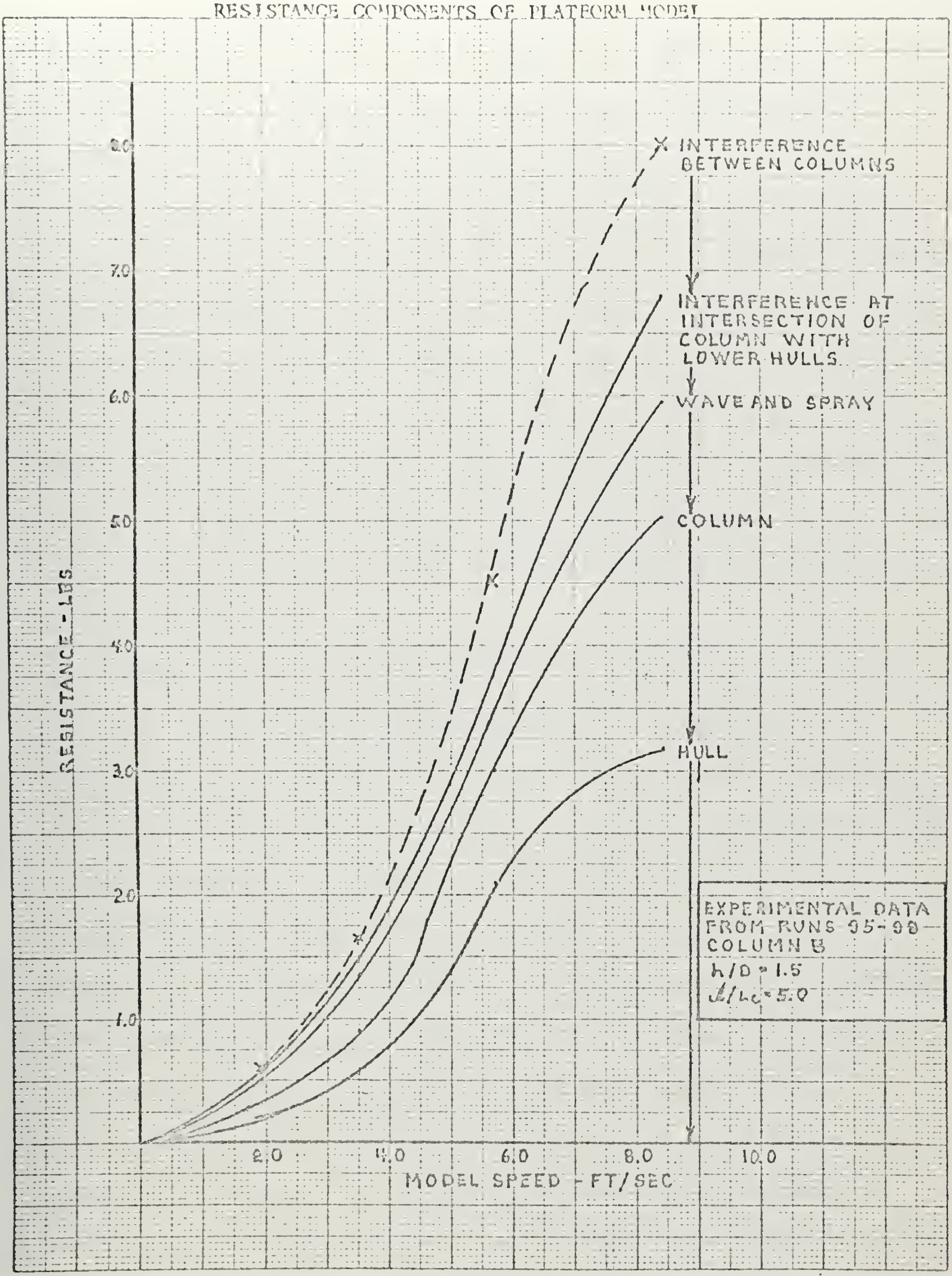


TABLE IV

DRAG COMPONENTS

Run Number	95	96	97	98
Velocity, ft./sec.	1.932	3.508	5.690	8.420
Hull Drag, lbs.	0.176	0.556	2.210	3.340
Column Drag, lbs.	0.126	0.370	0.790	1.710
Wave Drag, lbs.	0.218	0.414	0.464	0.890
Interference Drag, lbs.	0.029	0.122	0.239	0.840
Total of Theoretical Calculated Drag, lbs.	0.549	1.462	3.703	6.780
Measured Drag, lbs.	0.602	1.685	4.525	8.000

FIGURE XIII
RESISTANCE COMPONENTS OF PLATFORM MODEL



4. Discussion of Results

In an experimental investigation, the accuracy of the results depends on the data obtained and the interpretation of that data. It was desired to obtain results from the towing tests that would allow an investigation of the interference resistance that existed between the columns. Figures XI and XII graphically display the results obtained. Comparison between the figures reveals considerable scatter in the data. It appears that the methods used to obtain total drag data at the M.I.T. Ship Model Towing Tank were not accurate enough to obtain conclusive results. Since figure XI shows much less scatter in the computed results than does figure XII, it will be used to illustrate the trends of the interference drag.

The scatter of data may be attributed to several factors. Even though two dampers were attached to the dynamometer, oscillations may have affected the readings. Much care was taken in ensuring a proper fit of the columns to the lower hulls. However, the interchanging of the column shapes could have resulted in a small improper fit, providing an increase in drag. In addition, the interference drag between the columns and the lower hulls, D_I, may not be just a function of thickness as it was taken to be. It seems highly probable that it may also be a function of submergence ratio. The theoretical assumptions used to determine the other drag components may also differ from the experimental resistance measured in the tests providing error in the computed column interference drag.

Figure XI shows a change in slope from increasing to decreasing in the resistance curve, occurring between Fr = 0.995 and Fr = 1.545. Table V on the following page shows that the crest of the generated transverse wave from the forward column will pass across the aft column as the velocity is increased between the above values of Froude numbers.

The results for ℓ/L_C ratio of 2.0 were not presented in this form shown in fig. XI and fig. XII. The results of testing at an ℓ/L_C ratio = 2.0 with column shape B are shown in figures V through VIII of Section II-2. The interference drag for an ℓ/L_C ratio of 2.0 appears to be less than the ℓ/L_C ratio of 3.0. Possibly ventilation effects behind the forward column reduces the pressure on the front of the after column at this short spacing. The transverse wave crests from the forward column forms aft the after columns at the short spacing distance, also, for Froude numbers of column shape B greater than 0.700.

The separation of drag components of the model in figure XIII demonstrates the relative importance of the various drag components at various speeds. At low speeds the highest resistances result from the hull drag and wave drag of the columns. At higher speeds, the hull drag, though still the largest contributor, decreases in percentage of the total drag. The sectional drag of the columns and the interference drags become of greater importance.

The total drag of the mobile column stabilized platform

TABLE V

CALCULATED DISTANCES FOR WAVE TROUGHS AND CRESTS FOR A TRANSVERSE WAVE CREATED BY A POINT DISTURBANCE

Velocity (ft./sec.)	Froude No. for Columns A,B,C	Froude No. for Column F	Trough (occurance behind disturbance)	Crest
1.932	0.526	0.421	2.46 in. 11.80 in.	7.14 in. 16.60 in.
3.570	0.955	0.763	7.86 in.	23.50 in.
5.690	1.545	1.350	20.20 in.	61.20 in.

Note: The distances are determined by use of the formula:

$$X = 3.4\ V^2/g\ (n + 1/2)$$

Where X equals the distance aft of the pressure point

and n = 0,2,4 for crests

n = 1,3,5 for troughs

The amplitudes of sucessive crests and troughs decrease in proportion to the distance from the origin, therefore, only the first waves formed are considered in the evaluation.

is compared to a conventional model of comparable displacement and length on fig. XIV. Table VI tabulates their pertinent characteristics. At high speeds, fig. XIV shows a considerable drag saving with the mobile column stabilized platform model, and a considerable drag penalty at low speeds. This is typical of previous studies of the type of vehicle.

TABLE VI

COMPARISON OF RESISTANCE PERFORMANCE

Model	4777A	PLATFORM	PLATFORM	PLATFORM
Length (ft.)	3.05	3.54	3.54	3.54
Diameter (ft.)		0.5	0.5	0.5
Beam (ft.)	.773			
Δ(lbs.)	167.60	110.98	115.13	112.29
$\Delta/(.01L)^3$	730.0	1115.0	1154.0	1170.0
Runs		91-94	119-122	293-296
Column Shape		B	B	F
Submergence Ratio, h/D		1.5	3.0	1.5
Velocity (knots)		Resistance (lbs.)		
1.0	.284			
1.144		.600	.855	.772
2.0	1.110			
2.082		1.805	2.110	2.622
3.0	3.280			
3.561		4.480	3.900	6.900
3.99	4.140			
4.98	17.600	8.125	9.180	10.350

FIGURE XIV
COMPARISON OF PERFORMANCE WITH STANDARD DAVIDSON LAB. MODEL NUMBER 4777A

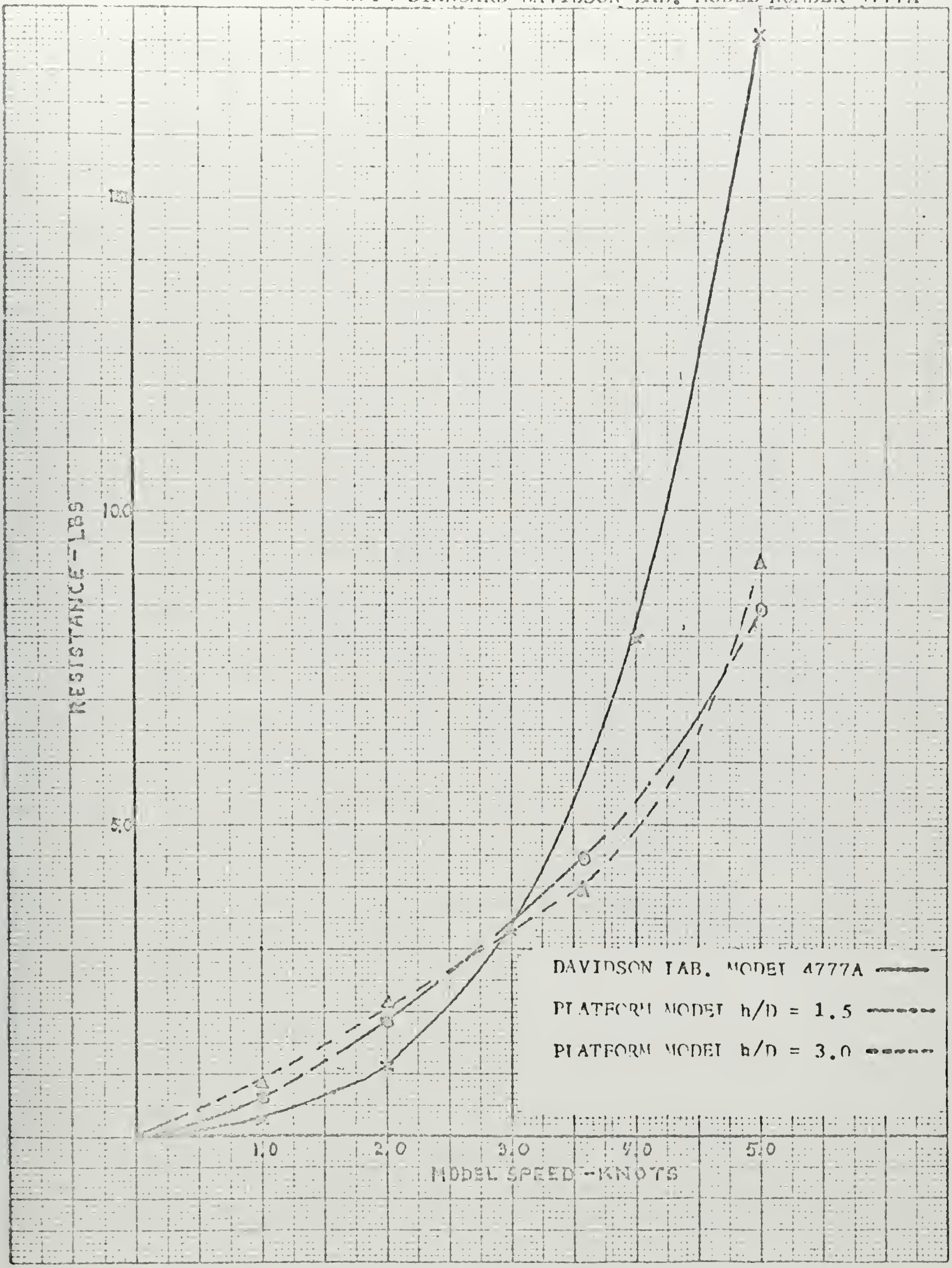
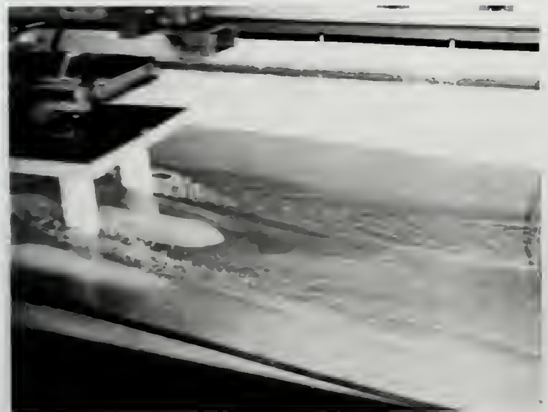


FIGURE XV

PHOTOGRAPHS OF MODEL



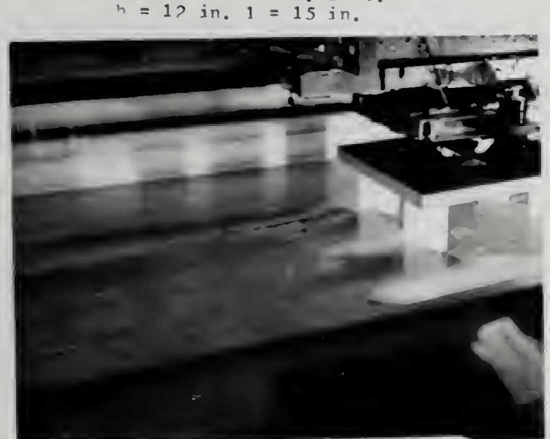
Col. A V = 4.97 kts.
h = 9 in. l = 15 in.

Col. F V = 2.06 kt.
h = 12 in. l = 22 in.

Col. A V = 3.31 kt.
h = 9 in. l = 15 in.

Col. D V = 3.31 kt.
h = 12 in. l = 15 in.

Col. F V = 2.06 kts.
h = 12 in. l = 22 in.



Col. F V = 2.06 kt.
h = 12 in. l = 22 in.

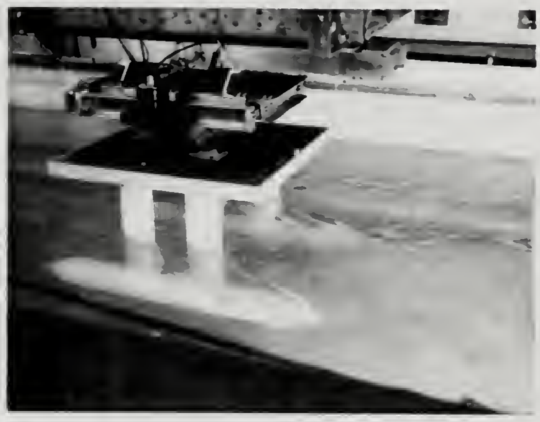
FIGURE XVI

PHOTOGRAPHS OF MODEL

Col. F V = 2.06 kt.
h = 12 in. l = 14 in.

Col. F V = 3.31 kt.
h = 12 in. l = 14 in.

Col. B V = 3.31 kt.
h = 12 in. l = 10 in.



Col. B V = 1.13 kt.
h = 12 in. l = 10 in.

Col. B V = 2.06 kt.
h = 12 in. l = 10 in.

Col. B V = 2.06 kt.
h = 17.[illegible] in. l= 10 in.

III. STABILITY

1. Procedure

One of the most severe constraints on the column stabilized platform is stability. In order to evaluate the various column forms and associated platform dimensions it was essential to select a particular configuration and set of dimensions for a full scale prototype. For this purpose, the general configuration of the model shown in figure XVII was assumed with a model to prototype scale ratio of 1:60. Characteristics of this prototype are given in Table VIII. The platform length and width conforms to the outer edges of the columns. The lower deck is completely enclosed by the main deck, and one half of the main deck is enclosed by deck houses. The main deck housing is at the fore and aft ends of the vessel. The total length of the columns is the submerged length (which is treated as a variable in the stability study) plus a fixed freeboard of thirty five feet for clearance of the platform above the waterline.

The prototype has to be a two draft vessel. It is ballasted to the deep draft position for transit in open seas and to shallower draft for operations in restricted waters.

Stability of the column stabilized platform may vary considerably as the draft is changed. Table VII on page 52 illustrates the stability for the design parameters that were used for sample calculations shown in Section III-4.

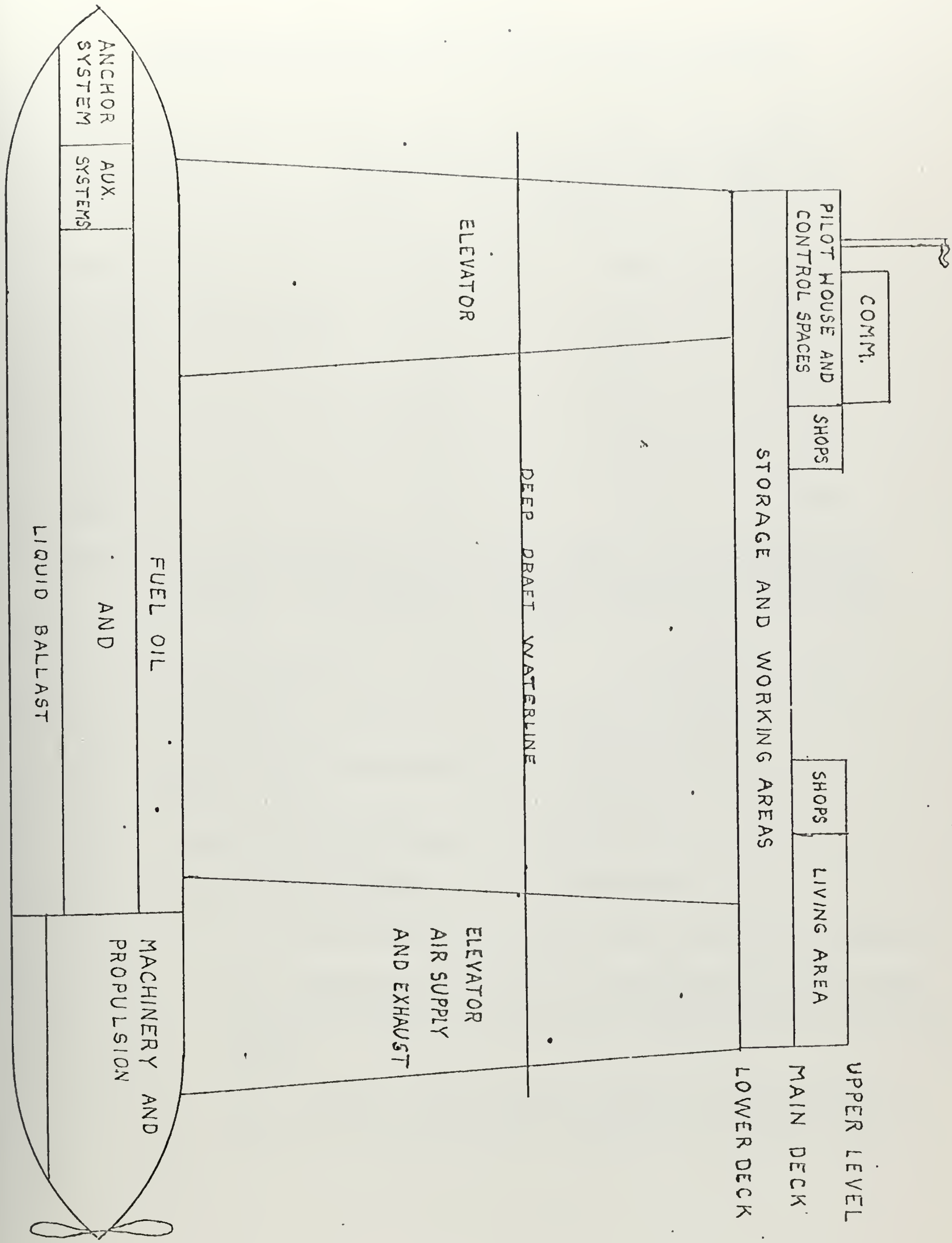

COMM.
PILOT HOUSE AND CONTROL SPACES
SHOPS
SHOPS
LIVING AREA
UPPER LEVEL
MAIN DECK
LOWER DECK
STORAGE AND WORKING AREAS
ELEVATOR
DEEP DRAFT WATERLINE
ELEVATOR AIR SUPPLY AND EXHAUST
ANCHOR SYSTEM
AUX. SYSTEMS
FUEL OIL
AND
LIQUID BALLAST
MACHINERY AND PROPULSION

TABLE VII

COMPARISON OF STABILITY WITH CHANGES IN DRAFT

Condition	I	II	III
Description	Lower hulls awash	Lower hulls just submerged	Deep sea transit condition
Draft, ft.	15.6	30.0	90.0
Displacement, tons	4060	6520	8515
KG, ft.	33.3	28.0	25.0
KB, ft.	10.1	15.0	24.6
BM, ft.	72.4	16.35	5.95
GM_T, ft.	49.2	3.35	5.55

Note: All computations were made using the parameters of the model for runs 67-70 of the data in Table I of Section II-2 with the columns tapered as described in Table IX of Section III-3:

Hull diameter, D = 30 ft.

Transverse spacing, b = 105 ft.

Max. design submergence ratio, h/D = 2.0

Longitudinal spacing, ℓ = 150 ft.

Conditions described in the Table are:

I - Vessel with no liquid loads and hulls exposed.

II - Vessel with fuel oil and potable water added in lower hulls to bring the water surface to the point of intersection of the columns with the lower hulls.

III - Vessel with ballast added to increase the draft to maximum design submergence ratio, h/D.

The vessel is extremely stable at the low draft with the lower hulls awash. The hulls provide a very large waterplane area offset from the centerline of the design. The large moment of inertia provides the vessel with stability characteristics similar to a catamaran vessel with a very high metacentric height. When the hulls become submerged, the column cross sectional area determines the stability of the vessel. The reduction in waterplane area lowers the height of metacenter above the center of buoyancy, BM. For a vessel having columns with constant cross sectional area, the BM would not change and the center of buoyancy above the keel, KB, would increase as ballast is added to the vessel. Therefore, if the added weight of ballast is low and does not raise the center of gravity above the keel, KG, the stability will improve. In this case, the stability of the design is most unfavorable when the intersection of the lower hulls and columns is at the water surface.

One way of providing adequate stability at the critical draft is to increase the column sectional area at the intersection with the lower hulls. It may then be tapered with decreasing cross sectional area up to the normal waterline for the deep draft position. The cross section of the columns may remain constant from the waterplane to the platform of continue to be tapered with decreasing cross sectional area up to the platform. This means of tapering the column enables stability conditions to be met at all drafts and at the same time minimizes added resistance and maintains high seakeeping ability.

To determine stability, prototype weights and their associated center of gravity were calculated as described in Section III-2. The increase in column size necessary to provide adequate stability at a draft of thirty feet was then calculated with an attempt ot provide at least a two and one half foot metacentric height. Two calculations were completed on each configuration. One was accomplished with the column tapered with decreasing cross sectional area to the waterline, and one with the taper extending up to the platform. The cross section of the columns where it met the upper platform was fixed to conform to the prototype dimensions taken from the model used in the resistance tests. The weights of the propulsion, structural, and fuel groups (which are functions of column length, column spacing, column shape, and the resistance associated with each configuration) were next determined. If the total calculated weight did not exceed the displacement of the lower hulls, various sizes of tapered columns, with the same L_C/t ratio, were examined to produce the combination most suitable for stability. If stability requirements permitted, additional payload was added at the main deck level. The summary of results is shown in Table IX, Section III-3. Since the methods used to determine stability are not given in any standard reference, a sample calculation is given in Section III-4.

2. Weights

The characteristics of the design studied in reference (9) are compared with the prototype vessel used in this study in Table VIII at the end of this section. The weights used for the stability and structural studies in Chapters III and IV were extracted from reference (9) and are presented in standard U.S. Navy weight groups. The following explains the determination of each weight group and its location on the vessel.

1) Structural weight was estimated by using the average of the range of coefficients presented in reference (11).

$$\text{weight of lower hulls} = 0.475\ \frac{(\text{VOLUME})\text{ft.}^3}{100}$$

$$\text{weight of columns} = 0.36\ \frac{(\text{VOLUME})\text{ft.}^3}{100}$$

$$\text{weight of upper platform} = 1/3\ (0.275)\ \frac{(\text{VOLUME})\text{ft.}^3}{100}$$

The upper platform is primarily of aluminum construction, therefore, according to company literature, the weight of the superstructure can be reduced by approximately one third as compared to steel.

2) Machinery weight was estimated for a diesel plant at 70 pounds/SHP(MAX.), at a horsepower corresponding to 30 knots speed. The machinery spaces are located in the lower hulls. Cruising SHP was determined from the model resistance data, assuming a cruising speed of 20 knots.

3) Electrical weight was estimated with the assumption that 3000 KW was required for the total electrical

load. 55 Tons is distributed uniformly in the platform and 176 tons in the lower hulls.

4) Comunications and control: 72 tons is distributed uniformly on the upper levels of the platform.

5) Auxiliary system:

   a. 330 tons in the lower hulls

   b. 50 tons distributed uniformly in the platform.

6) Outfit and furnishings: 220 tons distributed uniformly in the platform.

7) Fixed ballast is located in the bottom of the lower hulls.

8) Variable loads:

   a. Fuel weight was calculated using the normal shafthorsepower. The total endurance fuel was estimated in accordance with DDS 9400-1-C Appendix B with an endurance of 6000 miles.

   b. Stores are located on the lower deck of the upper platform and total 45 tons.

   c. Potable water totals 45 tons located in the lower hulls.

   d. Complement weight is 22 tons distributed uniformly over the platform.

9) Additional payload: varies with each design as permitted by the stability constraints and is located at the main deck level.

TABLE VIII

TABULATED DATA OF SCAMP VEHICLES

	Configuration Used in Reference (9)	Configuration Using Prototype to Model 60:1 Scale Ratio
Shallow Draft Conditions:		
Displacement, (tons)	6000	6520
Draft, (feet)	33.0	30.0
Deep Draft Conditions:		
Displacement, (tons)	6850	Varies
Draft, (feet)	99.0	Varies
Upper Platform Size	120 ft. x 120 ft. x 20 ft.	Varies
Column Dimensions:		
Length, L_C, (feet)	30.0	Varies
Width, t, (feet)	5.0	Varies
Shape	Doubly Symmetrical foil. Constant Cross Section over the entire Vertical Length	Varies
Longitudinal Spacing, ℓ (feet)	90.0	Varies
Underwater Hull Shape:	Series 58 Body of Revolution	Model shown in Fig. I
Length, (feet)	225.0	212.5
Beam, (feet)	32.0	30.0
Submergence Ratio, h/D	3.0	Varies

TABLE VIII

TABULATED DATA OF SCAMP VEHICLES

	Configuration Used in Reference (9)	Configuration Using Prototype to Model 60:1 Scale Ratio
Total Complement	182	182
Endurance Speed, (knots)	20	20
Maximum Speed, (knots)	30	30
Endurance, (miles)	6000	6000
Minimum Payload Weight, (tons)	905	Varies

3. Summary of Results

The following, Table IX, is a summary of stability calculations. In all cases, the column cross section at the intersection with the platform conformed to the column size tested in the model scale. The table states whether or not the configuration meets the stability requirements for a metacentric height of 2.5 feet at both design drafts. The sum of the weights given in Table IX for the shallow draft condition in all cases equals 6520 tons, the displacement of the scaled up prototype in the shallow draft condition given in Table VIII.

The increases in the column cross-sectional area (with the accompanying increases in structural, fuel, and machinery weights) were actually made for the designs tabulated in Table IX up to the point where the fixed shallow draft displacement of 6520 tons was exceeded. It was increased in steps of one fourth the original area using the model-prototype ratio of 1:60. The column cross sectional area and taper used in the calculations just prior to the point where the displacement was exceeded are presented in Table IX. The difference between the calculated weight and the displacement was added as solid ballast to give each design a fixed shallow draft of thirty feet and displacement of 6520 tons. This displacement includes all weights less the variable ballast.

In the designs that had values of metacentric height above the minimum requirement of 2.5 feet for both draft conditions, the feasibility of adding an additional payload

was investigated. Where it was added, it was included in the shallow draft displacement of 6520 tons.

For the designs with unsatisfactory stability, larger column cross sectional areas would be desireable to improve stability. However, this requires increased structural, fuel and machinery weights that would result in a larger value for the shallow draft.

Other methods may be employed to meet stability requirements. Some methods that may be used are to decrease platform size, lower endurance speed, etc.

The numerals in parentheses in Table IX have the following meanings:

Numeral (1) Constant column cross section from waterline to platform.

Numeral (2) The column is tapered its entire length up to the platform with a decreasing cross sectional area.

TABLE IX

RESULTS OF STABILITY CALCULATIONS

Run No. (see Table I)	1-4	5-8	9-12
Column Shape	A	A	A
Transverse Spacing, b (ft.)	105.0	90.0	75.0
Design Max. Hull Submergence, h (ft.)	88.75	88.75	88.75
Endurance (miles)	6000.0	6000.0	6000.0
Weight (tons):			
Group 1	1671.3	1670.8	1668.0
Group 2	1182.0	1195.0	1207.0
Fuel	2621.2	2491.0	2603.0
Fixed Ballast	25.5	143.2	42.0
Additional Payload at Main Deck	0.0	0.0	0.0
Fixed Weights (Groups 3,4,5,6, stores and complement)	1020.0	1020.0	1020.0
	6520.0	6520.0	6520.0
Column Dimensions (ft.)			
L_C (at lower end)	50.0	53.1	56.3
t (at lower end)	10.0	10.6	11.2
L_C (DWL for T = h+30')	25.0 (1)	25.0 (1)	25.0 (1)
t (DWL for T = h+30')	5.0	5.0	5.0

TABLE IX

RESULTS OF STABILITY CALCULATIONS

Run No. (from previous page)	1-4	5-8	9-12
Shallow Draft - 30 feet (ft.):			
KG	32.8	31.7	31.2
KB	15.0	15.0	15.0
BM	14.0	11.6	8.9
GM_T	- 3.8	- 5.1	- 7.3
Deep Draft (ft.):			
KG	28.9	27.8	26.9
KB	23.0	23.8	24.3
BM	3.5	2.58	1.78
GM_T	- 2.4	- 1.42	- 0.82
Variable Ballast (to submerge to deep draft, in tons)	1840.0	2022.0	2186.0
Platform Area ($ft.^2 \times 10^4$):			
Exposed	1.95	1.73	1.35
Enclosed	2.92	2.59	2.021
Stability Acceptable	NO	NO	NO

Run No. (see Table I)	13-16	17-20	21-24
Column Shape	A	A	A
Transverse Spacing, b (ft.)	75.0	90.0	105.0
Design Max. Hull Submergence, h (ft.)	60.0	60.0	60.0
Endurance (miles)	6000.0	6000.0	6000.0
Weight (tons):			
Group 1	1538.1	1535.6	1502.4
Group 2	1511.0	1540.0	1440.0
Fuel	2370.0	2416.2	2460.0
Fixed Ballast	80.9	8.2	1.6
Additional Payload at Main Deck	0.0	0.0	0.0
Fixed Weights (Groups 3,4,5,6, stores and complement)	1020.0	1020.0	1020.0
	6520.0	6520.0	6520.0
Column Dimensions (ft.):			
L_C (at lower end)	66.1	50.0	56.1
t (at lower end)	13.2	10.0	11.2
L_C (DWL for T = h+30')	25.0 (1)	25.0 (1)	30.3 (2)
t (DWL for T = h+30')	5.0	5.0	6.06

Run No. (from previous page)	13-16	17-20	21-24
Shallow Draft - 30 feet (ft.):			
KG	26.8	27.0	27.8
KB	15.0	15.0	15.0
BM	12.45	10.3	17.5
GM_T	0.65	- 1.7	4.7
Deep Draft (ft.):			
KG	24.1	25.3	25.2
KB	24.4	23.0	24.2
BM	1.78	2.58	3.5
GM_T	1.98	0.28	2.5
Variable Ballast (to submerge to deep draft, in tons)	1990.0	1590.0	2095.0
Platform Area ($ft.^2$ X 10^4):			
Exposed	1.35	1.73	1.95
Enclosed	2.021	2.59	2.92
Stability Acceptable	NO	NO	YES

Run No. (see Table I)	25-28	29-32	33-36
Column Shape	A	A	A
Transverse Spacing, b (ft.)	105.0	90.0	75.0
Design Max. Hull Submergence, h (ft.)	45.0	45.0	45.0
Endurance (miles)	6000.0	6000.0	6000.0
Weight (tons):			
Group 1	1514.2	1573.4	1588.0
Group 2	1410.0	1425.0	1422.0
Fuel	2480.0	2383.0	2389.0
Fixed Ballast	95.8	119.6	101.0
Additional Payload at Main Deck	0.0	0.0	0.0
Fixed Weights (Groups 3,4,5,6, Stores and complement)	1020.0	1020.0	1020.0
	6520.0	6520.0	6520.0
Column Dimensions (ft.):			
L_C (at lower end)	67.2	67.2	70.5
t (at lower end)	13.4	13.4	14.08
L_C (DWL for T = h+30')	36.5 (2)	36.5 (2)	25.0 (1)
t (DWL for T = h+30')	7.3	7.3	5.0

Run No. (from previous page)	25-28	29-32	33-36
Shallow Draft - 30 feet (ft.):			
KG	24.0	24.8	26.7
KB	15.0	15.0	15.0
BM	14.0	12.4	14.2
GM_T	5.0	2.6	2.5
Deep Draft (ft.):			
KG	23.5	23.2	24.2
KB	23.0	20.5	21.8
BM	3.01	6.1	1.78
GM_T	2.51	2.9	- 0.42
Variable Ballast (to submerge to deep draft, in tons)	1043.0	1125.0	1536.0
Platform Area ($ft.^2 \times 10^4$):			
Exposed	1.95	1.73	1.35
Enclosed	2.92	2.59	2.021
Stability Acceptable	YES	YES	NO

Run No. (see Table I)	55-58	59-62	63-66
Column Shape	C	C	C
Transverse Spacing, b (ft.)	75.0	90.0	105.0
Design Max. Hull Submergence, h (ft.)	88.75	88.75	88.75
Endurance (miles)	6000.0	6000.0	6000.0
Weight (tons):			
Group 1	1579.5	1573.0	1577.0
Group 2	1307.0	1462.0	1307.0
Fuel	2195.0	2280.0	2197.5
Fixed Ballast	318.5	185.0	318.5
Additional Payload at Main Deck	0.0	0.0	0.0
Fixed Weights (Groups 3,4,5,6, stores and complement)	1020.0	1020.0	1020.0
	6520.0	6520.0	6520.0
Column Dimensions (ft.):			
L_C (at lower end)	35.3	35.3	35.3
t (at lower end)	8.83	8.83	8.83
L_C (DWL for T = h+30')	25.0 (1)	25.0 (1)	25.0 (1)
t (DWL for T = h+30')	6.25	6.25	6.25

Run No. (from previous page)	55-58	59-62	63-66
Shallow Draft - 30 feet (ft.):			
KG	28.1	31.1	29.8
KB	15.0	15.0	15.0
BM	4.8	8.7	11.9
GM_T	- 8.3	- 7.4	- 2.9
Deep Draft (ft.):			
KG	27.1	29.6	28.9
KB	22.82	22.82	22.82
BM	2.4	4.35	5.95
GM_T	- 1.88	- 1.43	- 0.13
Variable Ballast (to submerge to deep draft, in tons)	1870.0	1870.0	1870.0
Platform Area ($ft.^2 X 10^4$):			
Exposed	1.6	1.82	2.05
Enclosed	2.4	2.73	3.08
Stability Acceptable	NO	NO	NO

Run No. (see Table I)	67-70	71-74	75-78
Column Shape	C	C	C
Transverse Spacing,			
b (ft.)	105.0	90.0	75.0
Design Max. Hull			
Submergence, h (ft.)	60.0	60.0	60.0
Endurance (miles)	6000.0	6000.0	6000.0
Weight (tons):			
Group 1	1640.5	1658.0	1506.5
Group 2	1590.0	1490.0	1595.0
Fuel	2415.0	2347.0	2398.5
Fixed Ballast	21.5	5.0	0.0
Additional Payload at			
Main Deck	0.0	0.0	0.0
Fixed Weights (Groups			
3,4,5,6, stores and			
complement)	1020.0	1020.0	1020.0
	6520.0	6520.0	6520.0
Column Dimensions (ft.):			
L_C (at lower end)	41.4	49.5	39.6
t (at lower end)	10.35	12.4	9.9
L_C(DWL for T = h+30')	25.0 (1)	25.0 (1)	25.0 (1)
t (DWL for T = h+30')	6.25	6.25	6.25

Run No. (from previous page)	67-70	71-74	75-78
Shallow Draft - 30 feet (ft.):			
KG	28.0	29.2	26.6
KB	15.0	15.0	15.0
BM	16.35	16.95	6.0
GM_T	3.35	2.75	-5.6
Deep Draft (ft.):			
KG	25.0	25.8	24.9
KB	24.6	24.1	21.4
BM	5.95	4.35	2.4
GM_T	5.55	2.65	- 1.1
Variable Ballast (to submerge to deep draft, in tons)	1470.0	1610.0	1475.0
Platform Area ($ft.^2 \times 10^4$):			
Exposed	2.05	1.82	1.6
Enclosed	3.08	2.73	2.4
Stability Acceptable	YES	YES	NO

Run No. (see Table I)	79-82	83-86	87-90
Column Shape	C	C	C
Transverse Spacing, b(ft.)	75.0	90.0	105.0
Design Max, Hull Submergence, h (ft.)	45.0	45.0	45.0
Endurance (miles)	6000.0	6000.0	6000.0
Weight (tons):			
Group 1	1525.7	1635.7	1598.2
Group 2	1535.3	1469.0	1552.0
Fuel	2440.0	2372.0	2349.0
Fixed Ballast	0.0	23.3	0.8
Additional Payload at Main Deck	0.0	54.6	298.0
Fixed Weights (Groups 3,4,5,6, stores and complement)	1020.0	1020.0	1020.0
	6520.0	6520.0	6520.0
Column Dimensions (ft.):			
L_C (at lower end)	50.0	50.0	50.0
t (at lower end)	12.5	12.5	12.5
L_C (at DWL for T = h+30')	25.0 (1)	38.1 (2)	38.1 (2)
t (at DWL for T = h+30')	6.25	9.55	9.55

Run No. (from previous page)	79-82	83-86	87-90
Shallow Draft - 30 feet (ft.):			
KG	22.2	28.5	34.8
KB	15.0	15.0	15.0
BM	9.6	17.4	23.8
GM_T	2.4	2.9	4.0
Deep Draft (ft.):			
KG	21.55	26.1	32.3
KB	20.6	20.9	21.2
BM	2.4	10.0	14.7
GM_T	1.45	3.8	3.9
Variable Ballast (to submerge to deep draft, in tons)	1575.0	1580.0	1580.0
Platform Area ($ft.^2 \times 10^4$):			
Exposed	1.6	1.82	2.05
Enclosed	2.4	2.73	3.08
Stability Acceptable	NO	YES	YES

Run No. (see Table I)	91-94	95-98	99-102
Column Shape	B	B	B
Transverse Spacing, b (ft.)	75.0	90.0	105.0
Design Max. Hull Submergence, h (ft.)	45.0	45.0	45.0
Endurance (miles)	6000.0	6000.0	6000.0
Weight (tons):			
Group 1	1520.7	1629.2	1598.3
Group 2	1505.0	1433.0	1381.0
Fuel	2360.0	2192.0	2122.0
Fixed Ballast	14.3	145.8	398.7
Additional Payload at Main Deck	0.0	100.0	425.0
Fixed Weights (Groups 3,4,5,6, stores and complement)	1020.0	1020.0	1020.0
	6520.0	6520.0	6520.0
Column Dimensions (ft.):			
L_C (at lower end)	56.0	56.0	56.0
t (at lower end)	14.0	14.0	14.0
L_C (DWL for T = h÷30')	25.0 (1)	41.4 (2)	41.4 (2)
t (DWL for T = h÷30')	6.25	10.35	10.35

Run No. (from previous page)	91-94	95-98	91-102
Shallow Draft - 30 feet (ft.):			
KG	24.0	29.2	36.0
KB	15.0	15.0	15.0
BM	11.8	17.8	24.3
GM_T	2.8	3.6	3.3
Deep Draft (ft.):			
KG	22.7	26.4	31.8
KB	21.38	20.8	23.2
BM	2.38	8.3	13.3
GM_T	1.01	2.7	4.7
Variable Ballast (to submerge to deep draft, in tons)	1545.0	1548.0	1548.0
Platform Area ($ft.^2 x 10^4$):			
Exposed	1.6	1.82	2.05
Enclosed	2.4	2.73	3.08
Stability Acceptable	NO	YES	YES

Run No. (see Table I)	103-106	107-110	111-115
Column Shape	B	B	B
Transverse Spacing, b (ft.)	105.0	90.0	75.0
Design Max. Hull Submergence, h (ft.)	60.0	60.0	60.0
Endurance (miles)	6000.0	6000.0	6000.0
Weight (tons):			
Group 1	1606.2	1628.6	1568.1
Group 2	1452.0	1506.0	1497.0
Fuel	2283.0	2370.0	2415.0
Fixed Ballast	158.8	0.4	19.9
Additional Payload at Main Deck	50.0	0.0	0.0
Fixed Weights (Groups 3,4,5,6, stores and complement)	1020.0	1020.0	1020.0
	6520.0	6520.0	6520.0
Column Dimensions (ft.):			
L_C (at lower end)	50.0	66.2	60.8
t (at lower end)	12.5	16.55	15.2
L_C (DWL for T = h+30')	35.6 (2)	25.0 (1)	25.0 (1)
t (DWL for T = h+30')	9.11	6.25	6.25

Run No. (from previous page)	103-106	107-110	111-115
Shallow Draft - 30 feet (ft.):			
KG	32.33	25.05	27.8
KB	15.0	15.0	15.0
BM	19.95	12.85	14.16
GM_T	2.62	2.8	1.36
Deep Draft (ft.):			
KG	27.9	23.6	24.3
KB	22.8	24.3	23.5
BM	10.3	3.55	2.36
GM_T	5.2	4.25	1.56
Variable Ballast (to submerge to deep draft, in tons)	1687.0	2163.0	1915.0
Platform Area ($ft.^2 \times 10^4$):			
Exposed	2.05	1.82	1.6
Enclosed	3.08	2.73	2.4
Stability Acceptable	YES	YES	NO

Run No. (see Table I)	116-119	120-123	124-127
Column Shape	B	B	B
Transverse Spacing, b (ft.)	75.0	90.0	105.0
Design Max. Hull Submergence, h (ft.)	88.75	88.75	88.75
Endurance (miles)	6000.0	6000.0	6000.0
Weight (tons):			
Group 1	1608.9	1624.2	1701.7
Group 2	1297.0	1288.0	1303.0
Fuel	2225.0	2219.0	2242.0
Fixed Ballast	169.1	168.8	103.3
Additional Payload at Main Deck	0.0	0.0	0.0
Fixed Weights (Groups 3,4,5,6, stores and complement)	1020.0	1020.0	1020.0
	6520.0	6520.0	6520.0
Column Dimensions (ft.):			
L_C (at lower end)	43.4	43.4	56.0
t (at lower end)	10.85	10.85	14.0
L_C (DWL for T = h+30')	25.0 (1)	25.0 (1)	25.0 (1)
t (DWL for T = h+30')	6.25	6.25	6.25

Run No. (from previous page)	116-119	120-123	124-127
Shallow Draft - 30 feet (ft.):			
KG	29.6	29.4	28.6
KB	15.0	15.0	15.0
BM	7.1	10.7	24.3
GM_T	-7.5	- 3.7	0.7
Deep Draft (ft.):			
KG	26.2	26.1	26.0
KB	24.6	24.6	25.3
BM	2.36	3.35	5.15
GM_T	0.76	1.75	4.15
Variable Ballast (to submerge to deep draft, in tons)	2020.0	2020.0	3060.0
Platform Area (ft.^{2} X 10^4):			
Exposed	1.6	1.82	2.05
Enclosed	2.4	2.73	3.08
Stability Acceptable	NO	NO	NO

4. Sample Calculation

The following sample calculation demonstrates the method employed to calculate stability using run number 67-70 of the data presented in Table I of section II-2.

Column C

Transverse spacing, b = 105 feet

Submergence of top of hulls, h = 60 feet

$\nu = 1.28 \times 10^{-5}$ for salt water at 59 degrees F.

$\nu = 0.938 \times 10^{-5}$ for fresh water at 79 degrees F.

In the following claculations subscript m refers to the model and subscript s refers to the prototype ship.

To determine SHP:

$$V_s = V_m\ 60 \quad ; \quad V_m = \frac{20 \times 1.689}{7.789} = 4.33 \text{ ft./sec.}$$

From resistance tests using overall surface area to determine C_{Dm}, coefficient of drag for the model:

$$C_{Dm} = .006604$$

$$Re_s = VL/\nu = \frac{33.7 \times 212.5}{1.28 \times 10^{-5}} = 5.6 \times 10^8$$

$$Re_m = VL/\nu = \frac{4.33 \times 3.54}{0.938 \times 10^{-5}} = 1.64 \times 10^6$$

$$C_{fs} = .075/[\log_{10} (5.6 \times 10^8) - 2]^2 = .00136$$

$$C_{fm} = .075/[\log_{10} (1.64 \times 10^6) - 2]^2 = .00422$$

With added roughness coefficient of .0004

$$C_{fs} = .00136 + .0004 = .00176$$

$$C_{rm} = C_{Dm} - C_{fm} = .006604 - .0042 = .002404$$

$C_{rs} = C_{rm}$

$C_{Ds} = C_{rs} + C_{fs} = .002404 + .00176$

$C_{Ds} = .004164$

$$EHP = \frac{C_{Ds}\ (\rho/2.0)\ (S_s)\ (V_s^{\ 3})}{550} \quad \text{where } S_s = S_m\ (3600)$$

$$= \frac{.004164\ (1.99/2.0)\ (44700)\ (33.8)^3}{550}$$

EHP = 12,600hp

p.c.= 0.74

$$SHP = \frac{EHP}{0.74} = 17,050 \text{ hp}$$

SHP from Appendage resistance = 6% (SHP) = 1020 hp

Cruising SHP = 18070 hp

Maximum SHP = 50600 hp

Summary of weights (see section III-2):

	Weight (tons)	KG (ft.)	Moment X 10^4 (ft-tons)
Group 1			
Hulls	1085.0	15.0	1.63
Columns	174.0	77.5	1.35
Platforms	229.5	131.7	3.02
Group 2	1270.0	12.0	1.52
Group 3	176.0	15.0	0.264
	55.0	132.0	0.726
Group 4	72.0	140.0	1.008
Group 5	220.0	132.0	2.9
Group 6	55.0	132.0	0.725
	330.0	15.0	0.525
	3666.5		12.668
Fuel	1610.0	13.0	2.09

Summary of Weights (continued)

	Weight (tons)	KG (ft.)	Moment X 10^4 (ft.-tons
Stores	45.0	130.0	0.585
Potable Water	45.0	15.0	0.068
Complement	22.0	132.0	0.29
	5388.5		15.673

Additional weight allowed: 6520 tons (at 30 foot draft)

-5388.5

1131.5 tons

Assume weight is solid ballast:

	WGT(tons)	KG (ft,)	Moment (ft.-tons X 10^4)
Solid Ballast	1131.5	3	0.344
	5388.5		15.673
	6520.0		16.017

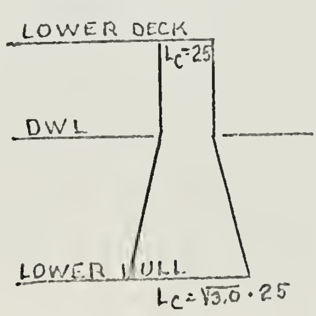
KB = 15.0 ft. 4(column area) = 492 ft.^{2}

distance to center of column from center axis, y = 52.5 ft.

required BM = KG - KB = 2.5 = 12.1 ft.

$BM = I/\nabla = 4Ay^2/\nabla = 5.95$ ft.

Area of the columns at the intersection with the hulls must be greater than 2.0 X area of the column using an assumed model to prototype ratio of 1:60. The area at the column base was increased 3.0 X original area. The column is tapered to the design waterline which is 90 feet from the keel.



Side View

Change of weights:

	WGT. (tons)	KG	Moment (ft-tons X 10^4)
Column	+232	61.7	1.43
Machinery	+390	12.0	0.468
Fuel	+490	13.0	0.658
Solid Ballast	-1120	3.0	-0.336
	0		2.210

Previous weights:

	WGT. (tons)		Moment (ft-tons X 10^4)
	6520		16.017
	6520		18.227

KG = 28.0 ft.

KB = 15.0 ft.

BM = 16.35 ft.

GM_T = KB + BM - KG = 15.0 + 16.35 - 28.0 = 3.35 ft.

To check at DWL:

	WGT. (tons)	KG (ft.)	Moment (ft-tons X 10^4)
KG: Ballast Added =	1895	15	2.84
	6520		18.227
	8415		21.067

KG = 25.0 ft.

KB:	Displaced WGT. (tons)	KB	Moment (ft-tons X 10^5)
	1460	60	0.876
	435	50	0.217
	6520		0.98
	8415		2.073

KB = 24.6 ft.

BM = 5.95 ft.

GM_T = KB + BM - KG = 24.6 = 5.95 - 25.0 = 5.55 ft.

Further increases in column cross sectional area to increase the metacentric height results in excess added weight to the vessel.

5. Discussion of Results

The study of stability summarized in Table IX indicates that in all cases the columns must have a larger cross sectional area throughout their length below the waterline than the columns assumed in the resistance tests. In the cases where additional weight is added to the main deck, columns could have met stability requirements with a smaller cross sectional area had the weight been added at a lower height above the keel in the design. For example, an additional liquid load could have been added in the lower hulls, if space permitted, with less of a penalty on stability. Tapering of the columns with a decreasing cross sectional area upward from the intersection of the columns with the lower hulls, will still enable them to meet the stability requirements and provide a minimum increase in resistance. As demonstrated in Table IX, in all cases studied, increasing the draft decreased the vertical distance between the center of buoyancy and the metacenter as a result of the smaller waterplane area. ~~Therefore, column shapes must be designed to change the center of buoyancy sufficiently, in order to provide a positive metacentric height after the additional payload or ballast has been added.~~

The transverse spacing should be as large as possible for the optimum stability. Increasing the transverse spacing beyond the longitudinal spacing of the column shifts the most critical stability to the longitudinal direction. From a stability and structural weight point of view, but not

necessarily from a resistance point of view, the submergence ratio, h/D, required should be low to permit shorter columns and lower center of gravity of the platform weights relative to the center of buoyancy.

In Table IX, all configurations using a maximum design submergence ratio, h/D, of 3.0 failed to meet the stability requirement that the metacentric height of two and one half feet be maintained at the two design drafts. Therefore, a lower design maximum submergerce ratio is desired to provide satisfactory stability for the design parameters of this study.

Though providing the largest waterplane area, the column shapes with the smallest length/thickness ratio are not necessarily the most favorable for the design. The advantage of increased stability from the larger waterplane area is diminished as a result of added structural weight and added resistance. On the other hand, the slender columns, with very high values of length/thickness, require a substantial increase in the cross sectional area to meet the stability requirements. This again increases structural weight and resistance. The design problem becomes one of tradeoffs to obtain optimum column size and shape.

IV. STRUCTURES

1. Procedure

Each configuration that maintained a positive GM in Section III-2 for the loads assumed and endurance required were used in the following structural study. Each set of parameters is referred to by the run numbers from data extracted from the model tests and listed in Section II-2. The purpose of this study is to determine the following:

1) The accuracy of the coefficients used for the column structural weights in Section III-2.
2) A comparison of structural requirements in the columns.
3) Additional bracing that may be required in the prototype vessel.

The use of the standard methods for determining hogging and sagging moments for a standard displacement vessel has little meaning for this design. The change in bending moments on the structures, resulting from a standard wave whose wave-length is equal to the ship's length and height equal to L/20, is insignificant. The small waterplane area causes only a slight change of the buoyancy curve. It was therefore necessary to determine the most detrimental condition of loading for this vessel.

A summary of the loads pertinent to column design is:

1) Weights
2) Buoyant forces
3) Hydrostatic pressure
4) Wind forces
5) Sea wave drag forces due to orbital wave vibration

6) Sea wave inertia forces due to orbital wave acceleration

7) Total drag forces

The most critical condition of loading was found during beam seas, with the inertia forces being dominant. The horizontal force can be written as:

$$F_I = C_M \rho \nabla (du/dt) \qquad (4.1)$$

where C_M = dimensionless inertia coefficient

ρ = density, lbs./ft.^{3}

∇ = volumetric displacement, ft.^{3}

and u = horizontal component of the water particle velocity, ft./sec.

From two dimensional potential theory the horizontal acceleration is:

$$(du/dt) = \frac{H}{2}\sigma^2 \exp\left[-(\sigma^2 y)/g\right] \cos(\sigma t - \sigma^2 x/g) \qquad (4.2)$$

where H = wave height, ft.

$\sigma = 2\pi g/\lambda$

y = vertical distance from mean waterline, ft.

t = time, sec.

x = horizontal distance from the wave crest, ft.

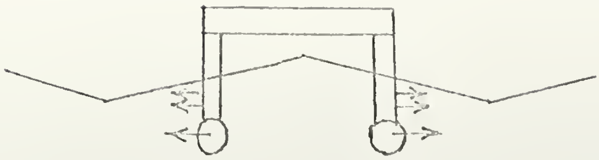
and g = 32.2 ft./sec.^{2}

By substitution, equation (4.1) becomes:

$$F_I = C_M \rho \nabla \frac{H}{2} \sigma^2 \exp -(\sigma^2 y)/g \cos(\sigma t - \sigma^2 x/g) \qquad (4.3)$$

This force is maximum when the phase angle is equal to 90 degrees or when the wave is one quarter the wave length away from maximum height. Thus, the most critical wave has a wavelength equal to transverse spacing between the columns

multiplied by four. The forces are exerted on the columns as shown below:



It was assumed that $C_M = 1.5$ (11) for all calculations. For the lower hulls the depth of water at which the wave force was acting was assumed to be at the mid point of the hulls, and for the columns, the forces were integrated over the length of the columns.

1) For the hull:

$$F_I = \rho C_M \nabla \frac{H}{2} \sigma^2 \exp(-\sigma^2 y/g) \tag{4.4}$$

2) For the column:

$$F_I = \rho C_M \left(\frac{H}{2}\right) \sigma^2 \int_0^Y \nabla \left[\exp(-\sigma^2 y/g)\right] dy \tag{4.5}$$

let A_1 = Area at $y = 0$

and A_2 = Area at $y = y(\text{max.})$

the formula becomes:

$$F_I = \rho C_M \left(\frac{H}{2}\right) \sigma^2 \int_0^Y \left[A_1 + \left(\frac{A2-A1}{y(\text{max.})}\right) y\right] \left[\exp(-\sigma^2 y/g)\right] dy$$

$$= \rho C_M \left(\frac{H}{2}\right) \sigma^2 \left[\int_0^Y A_1 \exp(-\sigma^2 y/g)\right] dy +$$

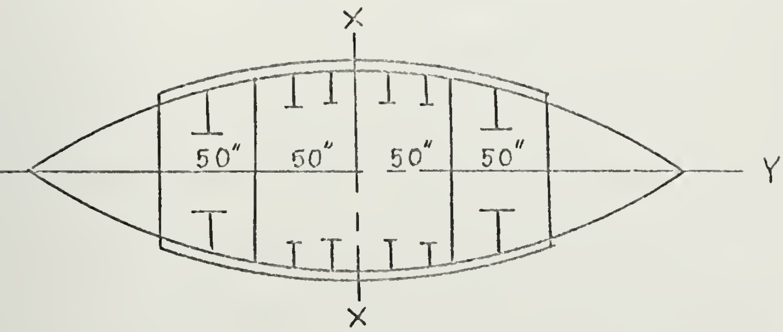
$$\int_0^Y \left(\frac{(A2-A1)}{y(\text{max.})}\right) y \left[\exp(-\sigma^2 y/g)\right] dy$$

The second integration was done by parts.

Table X lists a summary of significant wave heights and wave lengths used for the calculations. A summary of forces is listed in Table XI for the lower hulls and in Table XII for the columns. With these forces, bending moments on the

column structure may be determined.

Transverse bracing extends from the platform to the column at the waterline. Without this bracing the problem of structural integrity becomes extremely difficult. The plating was distributed below the waterline in accordance with the following diagram:



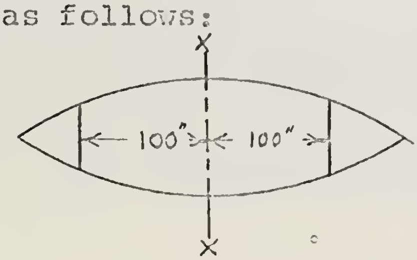
3/4 inch plate

outer plate varied to meet structural requirements.

inner section scantlings 25-6I 17½ beams each side.

outer section along y-y axis scantlings 15-18I 70 beams each side.

The scantlings in the center section are smaller to allow enough clearance for passage through the column. The upper section of the column, above the intersection with bracing, is as follows:



all plating 3/4".

The column was assumed to be rigidly fixed at the point where it is braced and act as a cantilever beam from that point down. Therefore, the maximum bending moment occurs at the waterline. Maximum bending stress is calculated by the relationship: $\sigma_b = \frac{Mc}{I}$ where c equals the distance from the axis to the outermost edge of the beams. Compressive stresses were calculated by the relationship: $\sigma_C = P/A$ where P equals the total weights and buoyant forces acting on the column, and A equals cross sectional area of the strength members of the column. The plating material assumed was mild steel with the following properties:

yield stress = 33,000 psi

Young's Modulus = 29×10^6 psi

density = 490 lbs./ft.^{3}

The support beams are American Standard I-Beam sections. Outer plating was added to the column for a longitudinal distance of 100 inches in order to meet all of the following requirements:

1) $1 = \frac{\sigma_b}{\sigma_{all}} + \frac{\sigma_c}{\sigma_{all}}$

σ_{all} = 18,850 psi for a factor of safety of 1.75.

2) Euler's formula to determine reduction in σcr for long columns:

$$\sigma cr = \frac{\pi^2 E}{(\ell/k)^2}$$

3) Compressive buckling:

$$\sigma cr = \frac{K_c \pi^2 E}{12(1-\upsilon^2)} \left(\frac{t}{b}\right)^2$$ page 72 of ref. (7).

4) Bending buckling:

$$\sigma cr = 0.285\ E(t/r)$$ page 37 of ref. (7).

A summary of the outer plating necessary and the structural weights of the columns are presented in Table XIV.

Cylindrical shell test data was used to determine the structural requirements of the lower hulls. Data was collected by Windenburg and Tulling (15), and plotted in terms of Ψ and λ. The Ψ value of unity seem desireable, and the corresponding value of λ is taken around 0.78 and 0.80. The pressure hull was designed for a pressure head with ten feet of the upper platform submerged, plus a safety factor of 1.5. With the above values of Ψ and λ, the thickness of the pressure hull and the distance between stiffening rings may be determined. The distance between stiffening rings is reduced by a factor of 1.2 for the curved ends. The stiffening ring to be used was calculated as outlined in ref. (3). The miscellaneous weights were calculated by using the U.S.S. Sea Lion (SS 315) as a parent ship. The ratio of new ship/parent ship was determined by the volume ratio. A summary of the hull weight calculations for each draft is presented in Table XIV.

2. Summary of Results

Table X of this section gives the assumed conditions to determine the critical loadings on the column stabilized platform. The structural weight of the two lower hulls varies from 870.16 tons for a prototype vessel with maximum submergence ratio of 1.5, to 1045.16 tons for a prototype vessel with h/d = 3.0. As the design submergence ratio is increased the column length is increased, since the height of the platform above the waterline remains constant for this design. The weights of the structural components in the columns increased with an increase in transverse spacing and increase in submergence ratios. The change in column weight was an average increase of only five to fifteen per cent in increasing submergence ratio from 1.5 to 2.0. The increase from 2.0 to 3.0 was eighty one per cent. Bracing was required in the transverse plane to the design waterline of the vessel. Tables XI through XIV present the results of the structural study.

TABLE X

CRITICAL WAVE CONDITIONS FOR VARIOUS TRANSVERSE SPACINGS

Transverse Spacing b(ft.)	Wave Length (ft.)	Significant Wave Height H_S (ft.)	Period (sec.)
75	300	30	7.2
90	360	35	8.4
105	420	45	9.06

TABLE XI

WAVE INERTIA FORCES ON LOWER HULLS

Transverse Spacing			
b =	75	90	105
Hull Submergence			
h			
45	1.311	1.56	2.062
60	.96	1.205	1.61
88.75	.656	1.04	1.091

Note: All forces are in pounds X 10^6.

TABLE XII

WAVE INERTIA FORCES ON EACH COLUMN

Runs (see Table I)	Force (lbs. X 10^6)
13-16	.374
17-20	.324
21-24	.316
25-28	.3043
29-32	.196
67-70	.436
71-74	.389
79-82	.3225
83-86	.754
87-90	.800
91-94	.510
95-98	.756
99-102	.536
103-106	.594
107-110	.509
111-115	.410
124-127	.542

TABLE XIII

STRUCTURAL WEIGHTS OF COLUMNS

Run (see Table I)	13-16	17-20	21-24	25-28	29-32	67-70
Column Shape	A	A	A	A	A	C
Transverse Spacing, b	75	90	105	105	90	105
Submerged ratio, h/D	2.0	2.0	2.0	1.5	1.5	2.0
Size of Outer Plate	2"	3"	4"	4"	2.5"	3"
Weight (tons):						
Outer Plate	75.2	112.4	136.6	113.0	70.5	112.4
3/4" Plate	27.9	27.9	27.9	20.9	20.9	30.0
Scantlings	84.0	84.0	84.0	61.4	61.4	84.0
Upper Section	28.6	28.6	28.6	28.6	28.6	30.4
Fairing	42.5	25.4	59.8	41.6	39.2	64.3
Total	257.2	278.3	336.9	265.5	220.6	321.1

Run (see Table I)	71-74	79-82	83-86	87-90	91-94	95-98
Column Shape	C	C	C	C	B	B
Transverse Spacing, b	90	75	90	105	75	90
Submerged ratio, h/D	2.0	1.5	1.5	1.5	1.5	1.5
Size of Outer Plate	2"	1½"	2"	4"	2"	2½"
Weight (tons):						
Outer Plate	75.0	42.4	55.4	110.8	56.2	70.5
3/4" Plate	30.0	22.5	22.5	22.5	21.7	21.7
Scantlings	84.0	61.4	61.4	61.4	61.4	61.4
Upper Section	30.4	30.4	30.4	30.4	28.9	28.9
Fairing	52.5	20.8	41.1	39.3	69.6	56.9
Total	271.9	177.5	210.8	264.4	237.8	246.8

Run (see Table I)	99-102	103-106	107-110	111-115	123-126
Column Shape	B	B	B	B	B
Transverse Spacing, b	105	105	90	75	105
Submerged ratio, h/D	1.5	2.0	2.0	2.0	3.0
Size of Outer Plate	3.5"	4.0"	3.0"	2.0"	2.5"
Weights (tons):					
Outer Plate	98.3	151.0	113.0	75.2	141.0
3/4" Plate	21.7	28.9	28.9	28.9	42.6
Scantlings	61.4	84.0	84.0	84.0	112.0
Upper Section	28.9	28.9	28.9	28.9	28.9
Fairing	64.3	34.8	89.4	69.6	180.0
Total	274.6	347.6	344.2	286.6	504.5

TABLE XIV

STRUCTURAL WEIGHT SUMMARY OF LOWER HULLS

Miscellaneous Weights for Two Hulls (Tons):

Tanks	6.55
Bulkheads	152.50
Main Deck	28.20
Upper Decks	47.50
Hull Fdns.	80.00
Doors, Hatches	24.20
Total	338.95

Summary Hull Structure:

Normal Draft (ft.)	45	60	88.75
Plating Thickness (in.)	7/16	5/8	11/16
Frame Spacing (in.)	12.45	19.46	21.544
Stiffener Ring	8I 18.4	10I 25.4	10I 35
Hull Weight (tons)	130	186	204
Stiffener Weight (tons)	135.6	119	149.4
Misc. Weight (tons)	169.48	169.48	169.48
Total, One Hull (tons)	435.08	474.48	522.88
Total, Two Hulls (tons)	870.16	948.96	1045.76

3. Discussion of Results

The lower hull weights decrease considerably with a decrease in the design maximum submergence ratio, h/D. This is demonstrated in Table XIV and is a result of the added pressure head on the exterior of the hulls when required to operate at a deeper depth. The column weights are not severely effected by the submergence ratios from 1.5 to 2.0, as shown in Table XIII. For example, the ratio equal to 2.0 in runs 17-20 of Table XIII is 278.3 tons. The same parameters and column shape were used in run 29-32, with the exception that the h/D is decreased to 1.5. In that run, the column weight is reduced to only 220.6 tons. When decreasing from h/D = 3.0, to 2.0, the effect on column weight is much greater. For example, in comparing runs 123-126 with runs 103-106, the parameters are the same with the exception of varying the maximum design submergence ratio from 3.0 to 2.0. The weight is decreased from 504.5 to 347.6 tons.

In comparing column shapes, the parameters of the prototype vessel used are h= 45 feet and transverse spacing, b, = 90 feet. This conforms to runs 29-32 for column shape A, runs 83-86 for column shape C, and runs 95-98 for column shape B. The resulting weights are:

Column A - 220.6 tons

Column C - 210.8

Column B - 239.4

Although column C shape is the most favorable for this condition, there is very little difference in the weights of the three shapes compared.

The coefficients used in the stability study to estimate the column structural weight are low. For example, from Section III-2 the total weight of the columns for runs 13-16 was estimated to be 522 tons, while Table XIII shows the total column weight of the four columns to be equal to 1028.8 tons. Therefore, the coefficient used to estimate the structural weight of circular columns will not give an accurate estimate of the structural weight of the slender columns. The relatively thin columns with smaller moments of inertia require very large plating thicknesses. Therefore, thicker columns, with smaller plating, are desireable to meet structural integrity.

The greatest effect on the structural weight of the columns is the amount of transverse bracing used. By adding bracing, the weight of the columns is reduced considerably.

V. CONCLUSIONS

The resistance data of this report indicates there is a significant interference resistance between the columns. Although the results were not conclusive, some observations cna be made from the data obtained.

The transverse spacing and depth of column submergence have very little effect on the value of the interference drag. A strong influence of longitudinal spacing and velocity on the interference resistance does exist. Although further confirmation is needed, the position of the transverse wave generated by the forward column relative to the after column appears to be instrumental in determining column interference resistance of the model.

For ships with low speed requirements the design of the lower hulls and the thickness of the columns are also critical in determining the total resistance. For higher speed ships the longitudinal spacing of the columns becomes more important in the design. In either case, the submergence ratio of the lower hulls is important. At low speeds it will determine the wave drag of the lower hulls, and at greater speeds the section drag of the columns is linearly proportional to the submergence ratio.

In comparison with a standard displacement ship, the new design has unfavorable resistance values at low speeds. However, at high speed, this design has possibilities of attaining lower resistance.

Columns with a slender thickness/chord ratio intended to minimize resistance will require a larger cross section

area where it joins the lower hull to provide adequate stability. The columns may, however, be tapered up to the waterline to minimize resistance. This will reduce the amount of additional structural weight, and should tend to reduce ship motion in waves. If added platform area is desired in the design, it should be added in the direction of smallest distance between the column centers, with the columns placed at the platform edges. This will increase the stability of the most critical condition, whether it may be transverse or longitudinal stability. The reason for the added stability is the increase in the moment of inertia of the waterplane area achieved by increasing the distance of the center of the waterplane area from the central axis. A design often is limited by other considerations, however, such as channel width and loading and unloading facilities.

If stability is unfavorable, it may also be improved by reducing the submergence ratio required for the full load condition.

As far as standard conditions are concerned, the most critical condition is when the vessel is experiencing beam seas with waves having wavelengths equal to four times the transverse distance between the column centers. The most effective way to reduce structural weight is to add bracing in the transverse direction. By lowering the point of intersection of the bracing with the column, the column weight can be reduced. However, lowering it below the normal waterline will increase resistance.

By reducing the maximum submergence ratio of the design in the full load condition, the lower hull structural weight is reduced because of the lower pressure head. The change in column weight with submergence ratio does not cause as large a change in the total structural weight as the change in lower hull structural weight. While the reduced length of the column reduces the weight of each structural member, larger plating scantlings are needed due to the increased wave inertia forces on the lower hulls. Increasing the sectional area of the column will reduce the scantlings of the plating required.

In summary, it is felt that the mobile column stabilized platform design definitely has possible merit in the field of naval architecture. However, the problems of the design are manifold and various studies need to be carried out to overcome them.

VI. RECOMMENDATIONS

To obtain conclusive results on the interference resistance, further studies are needed. It is recommended that resistance tests of columns attached to an end plate be conducted in further studies. There is data available on single strut and plate configurations, and a comparison of this data with tests using more than one strut attached to a plate is desireable to determine interference drag. A comparison with the results of this paper can then be made.

Since the column structures without bracing are inadequate, a resistance study on various bracing configurations that pierce the surface of the water should be carried out. Bracing was not included in the resistance tests even though at large values of transverse spacing, bracing would be required.

A study of the added resistance on the vessel while transiting in waves should be studied. It is expected that this will result in a very favorable characteristic for this design, when compared with a standard displacement vessel.

The effect of tapering of the columns on the resistance characteristics must be investigated. This paper only shows the results of tests conducted with the columns having a constant cross sectional shape.

The many tradeoffs of this design make it a likely candidate for computer programming. Such programming should be carried out after appropriate input data has been developed.

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